UNCLASSIFIED

AD NUMBER

AD870737

NEW LIMITATION CHANGE

TO

Approved for public release, distribution unlimited

FROM

Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; MAR 1970. Other requests shall be referred to Rome Air Development Center, AFSC, Griffiss AFB, NY.

AUTHORITY

RADC USAF ltr, 18 Jul 1963

THIS PAGE IS UNCLASSIFIED

26

RADC-TR-69-2
Final Technical Report
March 1970

RADIO FREQUENCY FENCE FOR GCA RADAR AT PHAN RANG, RVN

PHASE I FEASIBILITY STUDY

ITT/Gilfillan Incorporated

Rome Air Development Center
Air Force Systems Command
Griffiss Air Force Base, New York

82

RADIO FREQUENCY FENCE FOR GCA RADAR AT PHAN RANG, RVN

PHASE I FEASIBILITY STUDY

R. J. Hanratty
L. H. Sacks
W. J. Hunter

ITT/Gifillan Incorporated

ABSTRACT

Two "simple" rf fences are recommended for installation at the Phan Rang GCA radar site to provide 20 db clutter rejection for the S-band ASR. The dimensions of the fences, their locations and performance are based on the clutter rejection requirements, clutter profile, and aircraft radar-approach paths. Modular construction techniques for the fences results in minimum cost, rapid fabrication, mobility, easy storage, and high mechanical performance. Double-mesh screening minimizes X-band attenuation through the fence so that the X-band PAR performance is not deteriorated by the fence. The universality of the fence design allows the fence to be individually tailored to the requirements of most sites where clutter return is a problem.

FOREWORD

This final report was prepared by ITT/Gilfillan Inc., Van Nuys, California, under Contract F30602-69-C-0069, Project 1559. Period covered was October to December 1968.

The individuals from ITT/Gilfillan who contributed substantially to this report were Messrs. R. J. Hanratty, L. H. Sacks, and W. J. Hunter.

The RADC project engineer was Mr. Alfonse A. DeSalvio (EMAFD).

Release of subject report to the general public is prohibited by the Strategic Trade Control Program, Mutual Defense Assistance Control List (revised 6 January 1965), published by the Department of State.

This report has been reviewed and is approved.

Approved: ALFONSE A. DESALVIO
Project Engineer

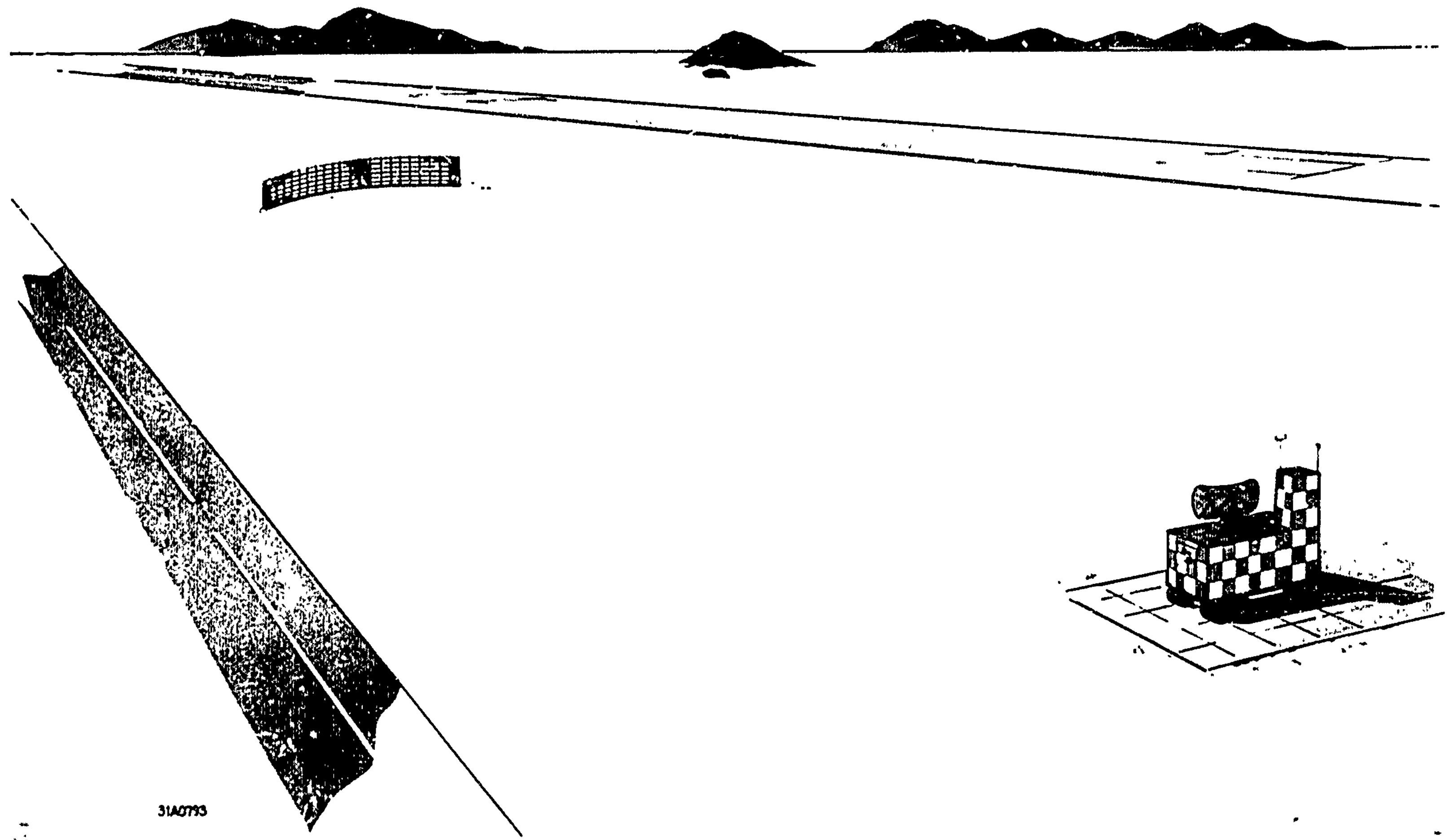
Approved: LEO W. SULLIVAN
Colonel, USAF
Ch, Surveillance and
Control Division

FOR THE COMMANDER: IRVING J. GABELMAN
Chief, Advanced Studies Group

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Cont.)



Frontispiece. RF Fence for GCA.

1. INTRODUCTION

This report presents the results of a study to determine the feasibility of adding rf clutter-reduction "fences" to the GCA radar site located at Phan Rang, RVN, to increase the signal to clutter ratio to an acceptable level. To achieve this objective, certain requirements were established for the fences. Among these are:

a. 20 db improvement in signal-to-clutter ratio at S-band.

b. 25 db two-way fence screening attenuation at S-band.

c. Less than 1 db two-way screening attenuation at X-band.

Decisions as to the feasibility of the fence for Phan Rang have been made by considering the trade-offs between cost, complexity and performance in the light of these requirements. This report discusses these factors and also provides the necessary information to choose an optimum fence, i.e., dimensions, location, etc. for Phan Rang and also for other sites.

The following section presents pertinent background information, and reviews the general problem. Section 3 describes alternative solutions to the problem and the factors that led to the selection of an rf fence.. In Section 4 is a general discussion of rf fences, and in Sections 5 through 8 the various types of fences and the several interrelated factors that need to be considered in their design are described. A specific recommendation of a fence for Phan Rang is made in Section 9, and its predicted performance is contrasted to that of the temporary fence at Phan Rang in Section 10. The last two sections discuss several other factors pertaining to the recommended fence including suggested construction techniques.

This study represents the first phase (Phase I) of an overall three-phase program sponsored by RADC. If the rf fence feasibility is established, Phases II and III will be, respectively, fabrication and installation of the fence, and on-site testing of the radar with the fence installed.

2. STATEMENT OF THE PROBLEM

The GCA radar at Phan Rang consists of an S-band air surveillance radar (ASR) and an X-band precision approach radar (PAR). The radars share a common site located about midway between the two parallel runways. Two problems currently exist with the S-band ASR at this location.

The first problem is direct clutter return to the radar from certain angular directions, caused by reflection of the transmitted signal from mountains and other terrain surrounding the radar site. The photograph of a contour map of the Phan Rang area shown in Figure 2-1 illustrates the mountainous nature of the terrain which has reduced the subclutter visibility of the radar to less than that desired. The second problem is the existence of multipath signals, caused by ground reflections between radar and target. These reflections have resulted in significant pattern lobing in elevation.

In each case, the problem is caused by a spurious signal path, which is at an elevation angle below that of the desired signal path. The basic problem then is to provide some means of discriminating against, or attenuating, the spurious signal path, while not affecting the direct signal path. System studies and on-site observations have indicated that at least 20 db rejection of the spurious signal path is required to reduce the clutter and multiplath effects to the level desired. The effect of a 20 db reduction in clutter is illustrated by the two PPI displays shown in Figure 2-2.

3A0793

Figure 2-1. Relief Map of Phan Rang Showing Radar Approach Path to Air Base

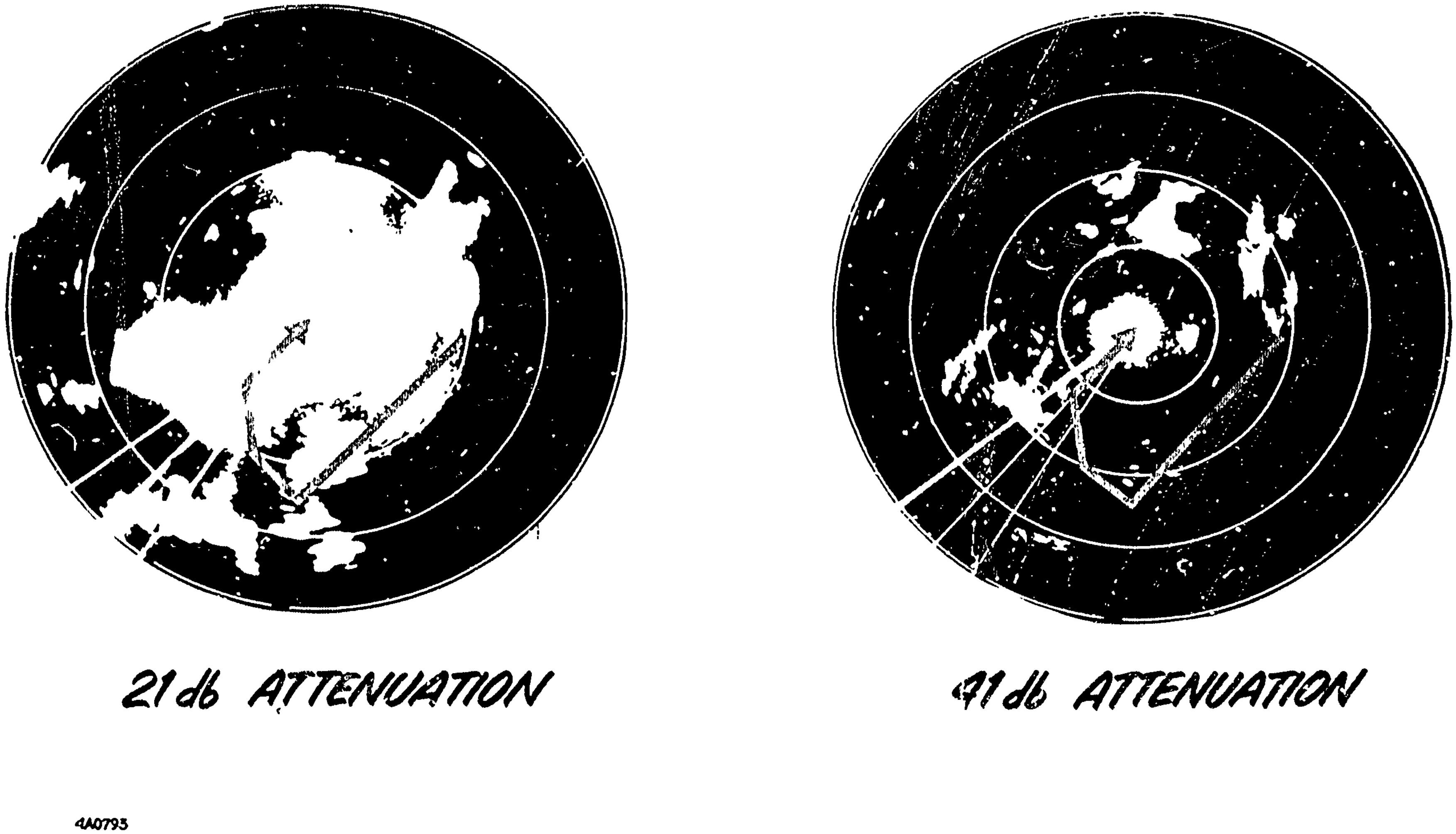


Figure 2-2. Clutter Photographs, Illustrating Effect of a 20-db Reduction in Clutter.

3. ALTERNATE SOLUTIONS AND SELECTION OF RF FENCE

While the above problems are different in cause, common solutions are available: (1) reshaping the antenna beam for reduced "bottom-side" response; (2) control of the radar site environment; or (3) a combination of both.

The first solution is ideal in the sense that it is not "tailored" to the particular radar site; however, it requires redesign of the antenna to increase the bottom-side "roll-off" of the beam. This is, therefore, not a short-term solution to the problem, but is the more desirable one for a longer time scale, since it has no effect on the performance of the X-band PAR.

The second solution can take the form of an electrically opaque fence in front of the radar to "block" the spurious signal path. This solution does not require any change in the existing antenna and can be accomplished on a short time scale. Its disadvantages are that it must be tailored to the particular radar site, it can affect the performance of the X-band PAR if not designed properly, it is not suitable for locations where ice and snow may be a problem, and its size limits its use in tactical environments. However, in the present case, an rf fence appears to be the simplest solution to the clutter and multipath problems, and is, therefore, the solution suggested by RADC for a feasibility study.

4. GENERAL APPROACH TO DESIGN OF AN RF FENCE

The design of an rf fence involves many different factors. In general, these are interrelated; occasionally they are in opposition to one another in the establishment of criteria for the fence design. In the present case the fence must be designed to block the spurious S-band signal paths with at least 20 db rejection, and yet not degrade the desired S-band signal paths, nor the various X-band signal paths. All this must be achieved within the geometric constraints imposed by the air-base environment. Some of the principal problems involved in fence design, which illustrate the various interrelated factors, are briefly discussed below.

Figure 4-1 illustrates the significant signal paths affecting the clutter return with and without a fence. Without a fence there is a direct clutter return from the environment in addition to the target return. With the addition of a fence, the clutter return is determined by signals diffracted over the fence, signals "leaked" through, and signals leaked under the fence. Each of these is controllable, respectively, by the height of the fence, the mesh used in its construction, and the depth of its insertion into the ground. In addition to the paths shown, there are many combinations of ground reflections with these paths. The clutter return is also determined by the shape of the fence as observed in a plan view of the site. The fence must generally be wider, by some margin, than the angular sector over which clutter rejection is required.

For a fixed geometry between the radar antenna, target, and clutter, the greatest rejection of clutter return, without significantly affecting the target return, is achieved by locating the fence as far from the antenna as possible, within the geometric constraints imposed by the site and the higher cost of the larger-radius and higher fence necessary to achieve this

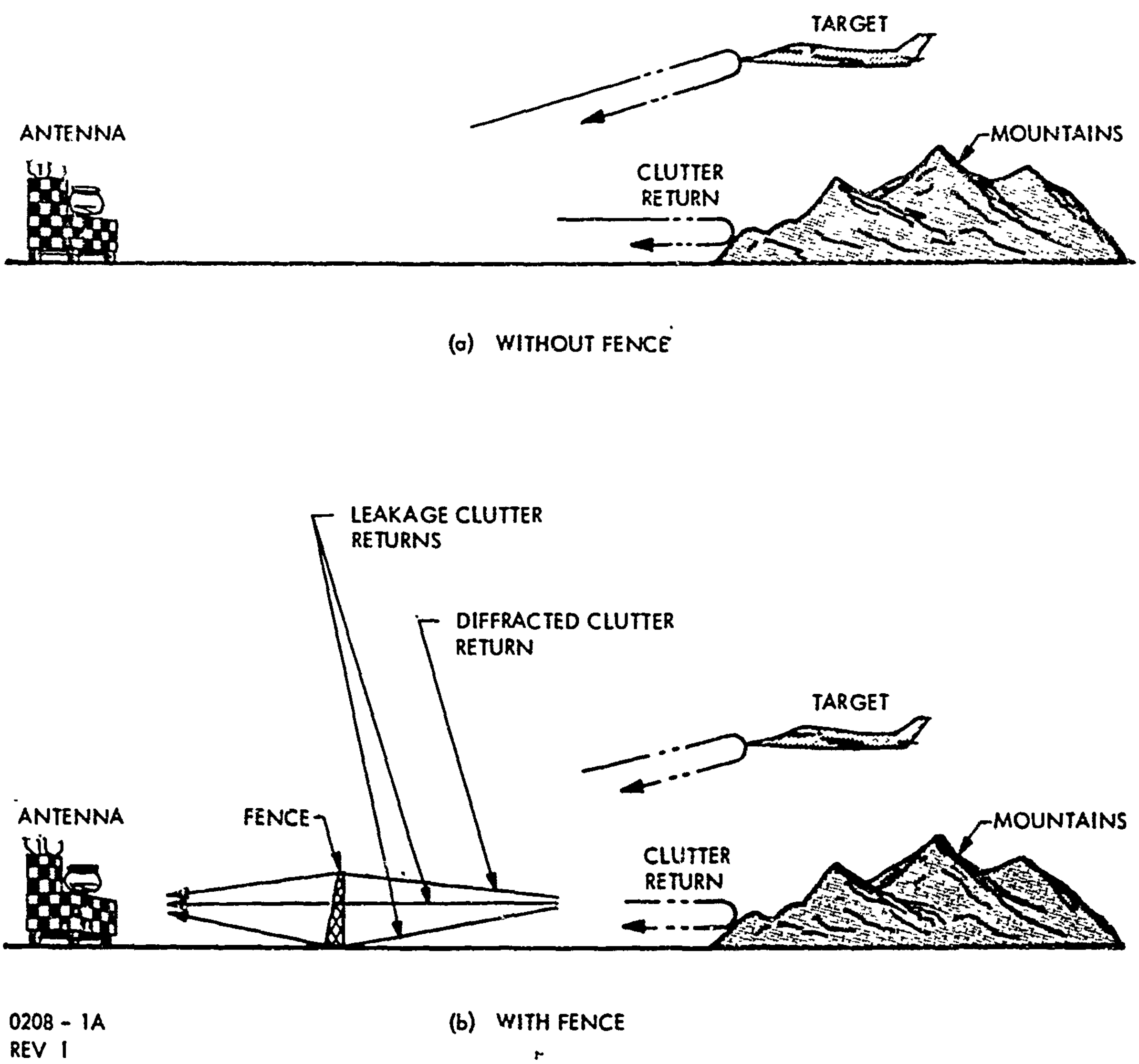


Figure 4-1. Significant Signal Paths Affecting Clutter Return

rejection. If the conditions for 20 db clutter rejection at S-band cannot be achieved without a significant target return effect, the fence height can be increased to increase the clutter rejection, at the expense of reduced aircraft target return at S-band.

Since any rf leakage through the fence will deteriorate its clutter rejection capabilities, the fence material must be electrically opaque at the S-band operating frequency of the ASR. A continuous metal sheet could eliminate all leakage but would be unsuitable for reasons of weight, cost, windloading, etc. A more practical solution is a mesh screen with the wires spaced close enough (fraction of a wavelength) to provide sufficient S-band attenuation.

Any fence installed for S-band clutter rejection might unavoidably affect the performance of the X-band PAR because of the proximity of the two radars to each other To minimize such performance degradation, the fence should be electrically transparent in those sectors where it encompasses the scan angle of the PAR. A wire mesh fence which is essentially opaque at S-band may not necessarily be electrically transparent at X-band even though there is a 3 to 1 frequency separation between the bands. To overcome this difficulty, several screens can be combined into a multiplayer fence. The S-band opacity and X-band transparency required for the Phan Rang site can then be achieved by utilizing the principles of a band-rejection filter.

A modification of the simple knife-edge fence approach is the application of edge-treatment techniques to the top of the fence. These can take the form of serrations, or single and multiple slots. With such treatment, the clutter rejection of the same-height simple fence can be increased, or the fence height can be reduced to maintain the original clutter rejection. A serrated fence edge is simple to construct, but

introduces undesirable grating lobes in azimuth directions; therefore, it has not been generally used. A single continuous slot, on the other hand, does not introduce grating lobes and provides a first-order cancellation of the edge-diffracted signals in the direction of the antenna. Two slots below the fence edge can yield a second-order cancellation of the edge-diffracted signals, and also enables operation over a wider range of clutter elevation angles.

Additional clutter rejection can be obtained by using multiple fences, i. e. two or more fences of different radii. The multiple fences can be of either the simple or edge-treated type.

The advantages of the edge-treated and multiple-fence approaches, however, are dependent on the aircraft target-clutter geometry. As the angular separation between the aircraft and clutter decreases, the additional clutter rejection can be achieved only by going to increasingly higher fences. The result is that the aircraft return is significantly suppressed at the low elevation angles and the "net" clutter rejection may be comparable at those angles to that obtainable using a simple fence of similar height.

5. PRINCIPLES OF SIMPLE FENCES

The "simple" fence will be defined as an opaque screen whose top edge is a thin (compared to a wavelength) straight-edge. The fence-antenna and reflected signal geometry are shown in Figure 5-1. The field near the geometric shadow for either polarization behind the fence can be determined from Sommerfeld's classic solution for half-plane or knife-edge diffraction, and is given by

$$E(\phi, \gamma) = \frac{e^{-j\pi/4}}{\sqrt{2}} \; e^{jkr\cos(\phi-\gamma)} \left\{ \left[\frac{1}{2} - C(X)\right] + j\left[\frac{1}{2} - S(X)\right] \right\} \quad (5.1)$$

where $X = 2\sqrt{\frac{2r}{\lambda}} \quad \sin\frac{(\phi - \gamma)}{2}$

$$C(X) = \int_0^x \cos\frac{\pi}{2} t^2 \, dt$$

$$S(X) = \int_0^x \sin\frac{\pi}{2} t^2 \, dt$$

E = electric field at center of antenna aperture

λ = wavelength in same units (feet, inches, etc.) as r

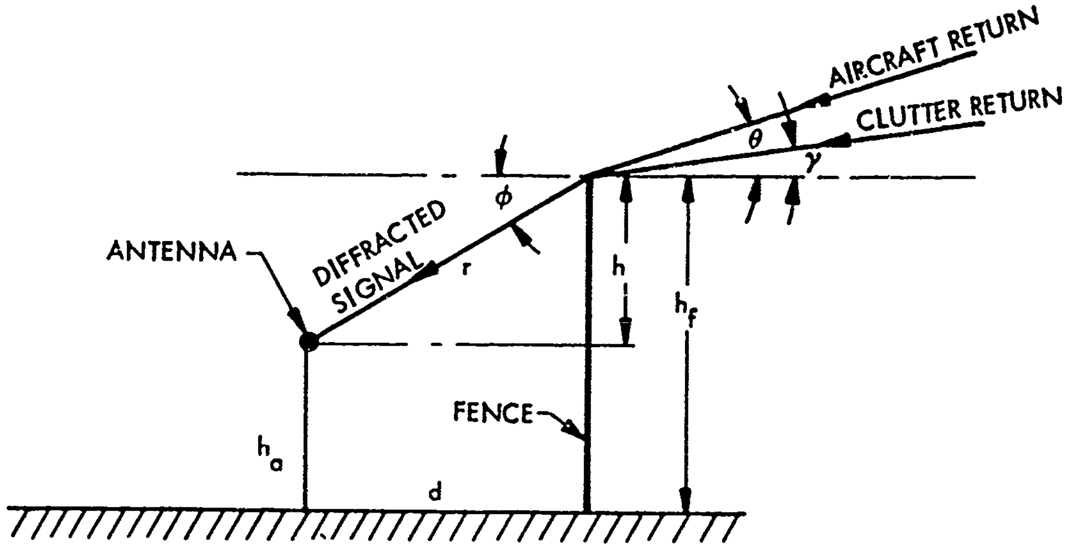
k = wave number = $\frac{2\pi}{\lambda}$

The functions C(X) and S(X) are the Fresnel integrals and have been extensively tabulated.

The field at the antenna aperture due to the signal reflected from the aircraft is given by $E(\phi, \theta)$ and is obtained by replacing γ in equation (5.1) by the aircraft elevation angle θ. At angles where the fence shadowing effect is negligible, the value of $E(\phi \;\; \gamma)$ becomes unity. $|E(\phi, \gamma)|$ and

$|E(\phi \;\; \theta|$, as determined by equation (5.1), are therefore ratios of the signals received with and without the fence and thus represent respectively the clutter and aircraft suppression.

Figure 5-1. Fence Geometry



793 - 4A

r = distance between center of antenna aperture and fence edge

h_a = height of antenna above ground

h_f = height of fence above ground

h = height of fence edge above center of antenna aperture

d = distance between antenna aperture and fence

ϕ = angle between diffracted ray from fence edge to center of antenna aperture and normal to fence

γ = angle between ray reflected from clutter source and normal to fence

θ = angle between signal reflected from aircraft to fence edge and normal to fence

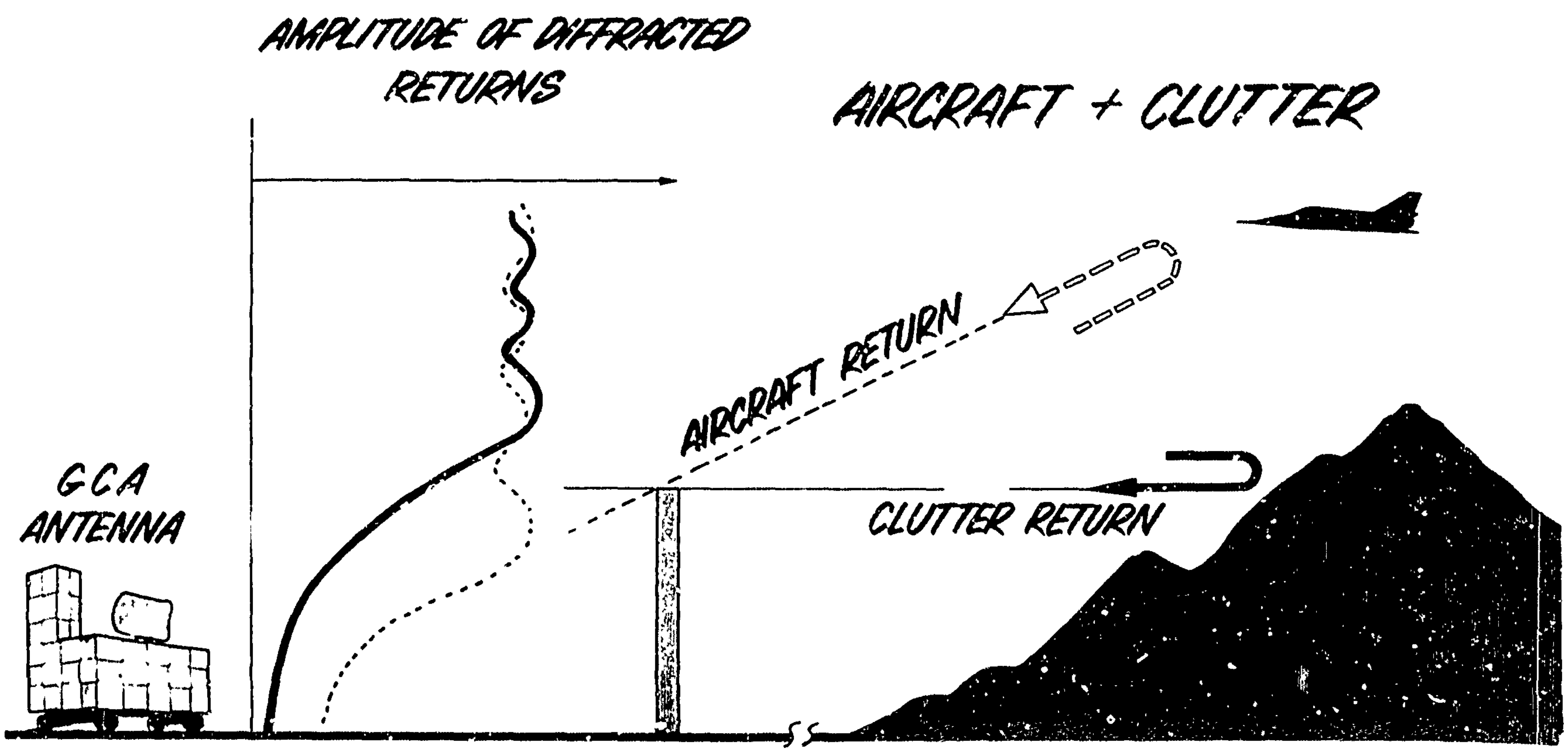
Since any aircraft target suppression will deteriorate the radar system performance, its effects must be included in the fence evaluation. This is done by defining the "net clutter suppression" as the ratio of clutter suppression to target suppression. The two-way net clutter suppression which describes the fence performance for the transmit-receive ray path is then obtained from equation (5. 1):

$$\text{Two-way net clutter suppression (db)} = -20 \log_{10} \frac{\left|E(\phi, \gamma)\right|^2}{\left|E(\phi, \theta)\right|^2} \tag{5.2}$$

The principle of operation of the simple fence is shown in Figure 5-2. The difference between the amplitudes of the diffracted returns from the aircraft and clutter which determines the net clutter suppression is illustrated in the figure.

An additional factor which must be taken into account is the relationship between the antenna-fence-clutter geometry and the antenna directivity pattern. If the angle at which the antenna beam intercepts the fence is different than the clutter angle, i. e. $\phi \neq \gamma$, then the diffracted return must be modified by taking into account the ratio of the antenna pattern gain in the direction of the fence compared to the gain in the direction of the clutter source with no fence present. Figure 5-3 shows the modification to the clutter suppresssion caused by different antenna gains in the directions ϕ and γ. For the example shown, the net two-way clutter suppression is reduced by 6 db due to the antenna gain factor. The reduction (or increase) of the target suppression is obtained in the same manner. Equation (5. 2) can be modified to include the antenna pattern directivity by multiplying the clutter and target suppression terms by the appropriate antenna gain factors, i. e.,

Figure 5-2. Amplitude of Diffracted Returns for Simple Fence



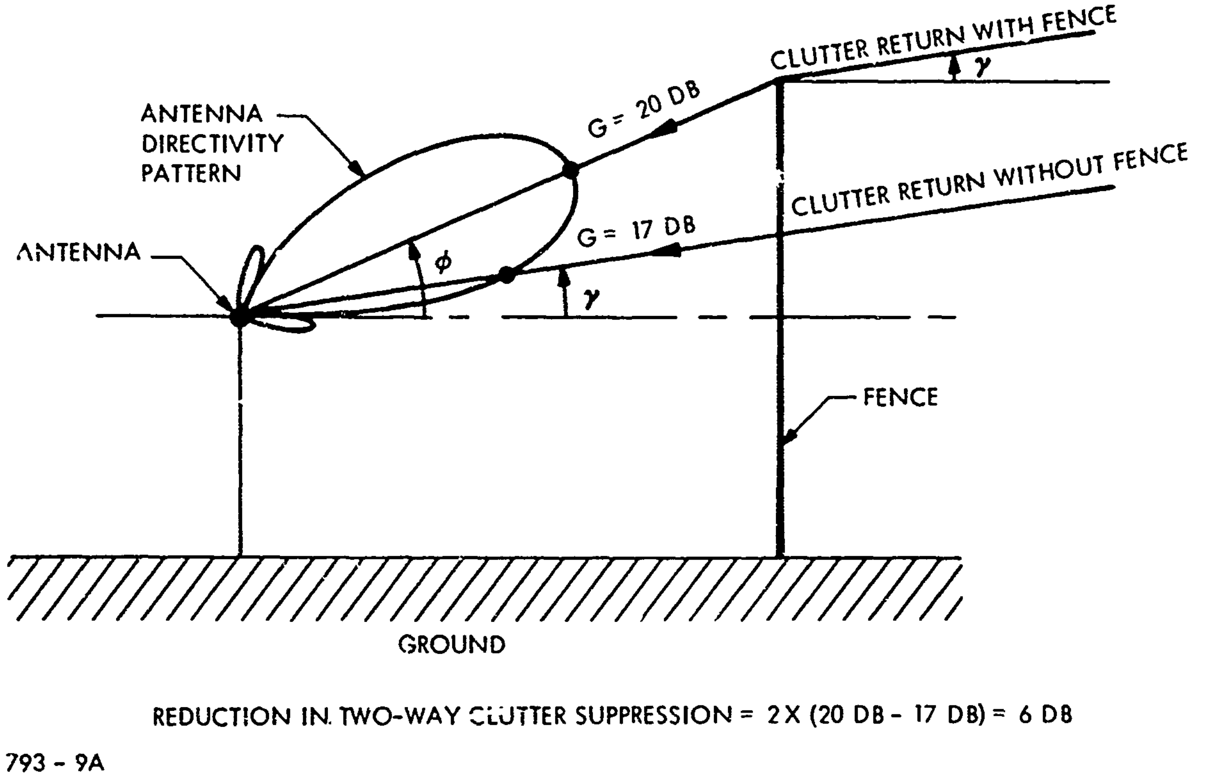


Figure 5-3. Example of Effect of Antenna Directivity Pattern on Clutter Suppression

$$\text{Two-way net clutter suppression (db)} = -20 \log_{10} \frac{|E(\phi,\ \gamma)|^2 \left|\frac{G(\phi)}{G(\gamma)}\right|}{|E(\phi,\ \theta)|^2 \left|\frac{G(\phi)}{G(\theta)}\right|} \qquad (5.3)$$

where

$G(\phi)$ = antenna power gain in ϕ direction

$G(\gamma)$ = antenna power gain in γ direction

$G(\theta)$ = antenna power gain in θ direction

For the higher elevation angles, where there is no fence shadowing, the antenna gain factor will not apply. At these angles, values of unity are assigned to the terms $\frac{G(\phi)}{G(\gamma)}$ and/or $\frac{G(\phi)}{G(\theta)}$.

Values of net clutter suppression were calculated for different aircraft elevation angles using equations (5.1) and (5.3). The clutter angles, antenna to fence distances, and fence heights were chosen so as to be applicable to sites such as Phan Rang. The effect of the fence on the antenna pattern was taken into account, as described above, for the case of the ASR antenna pointed 6 degrees above the horizon operating at a frequency of 2.8 GHz.

Curves of two-way net clutter suppression were plotted for values of clutter angle, γ, of 0, 0.5, 1.0 and 1.5 degrees, and for antenna to fence distances, d, of 100, 200, 300, 400, 800 and 1600 feet. These curves are included in the Appendix and can be used to determine the required fence parameters for different antenna sites for which the clutter profile and aircraft flight geometry are known. The technique for determining the fence parameters from the curves is discussed in Section 9.

6. PRINCIPLES OF COMPLEX FENCES

Complex fences employ edge-treatment techniques to the top of the fence to attenuate the diffracted clutter power. These can take the form of serrations, or single and multiple slots. The serrated and single slotted edge-treatments are illustrated in Figure 6-1.

The principle of operation of the complex fence is readily understood by referring to Figure 6-2. The field diffracted over the top edge of the fence in the direction of the center of the antenna aperture is split into two or more paths whose amplitudes are adjusted by varying the serration or slot dimensions. These path lengths can also be made, by proper choice of the serration or slot dimensions, to differ by one-half wavelength. The serrated or single slotted edge can thus provide a first-order cancellation of the diffracted fields at the antenna aperture, and two slots can yield a second-order cancellation of the fields. This results in increased clutter suppression relative to the simple straight-edge fence design. The suppression of complex fences is limited by their frequency and polarization sensitivity, their physical constraints, and by the fact that complete field cancellation cannot occur over the antenna total aperture area. A further limitation of the serrated fence edge is that it introduces undesirable grating lobes in azimuth directions.

The advantage of the complex fence approach is dependent on the aircraft flight path and clutter profile. As the angular separation between the aircraft and clutter decreases, the antenna to fence angle, ϕ, must become smaller to prevent aircraft suppression. The serration or slot depth, Δh (see Figure 6-2), required to provide phase cancellation at the antenna aperture however is inversely proportional to "$\phi - \gamma$". For small aircraft elevation angles the serration or slot depth, and therefore the total fence height, $h + \Delta h$, can become prohibitively large. Furthermore, selection

of a small basic fence height, h, will not help the problem since as h decreases so does ϕ, and the required serration depth Δh must increase proportionally. This is illustrated in Figure 6-3, which shows the total fence height (above antenna) vs. h for the cases of d = 400 ft., $\gamma = 0.5^{\circ}$ and d = 800 ft., $\gamma = 0.5^{\circ}$ and 1.0°.

Typical performance of a serrated fence is shown in Figure 6-4. The fence height of about 14 feet is the minimum height which can provide cancellation of the diffracted fields at the center of the antenna aperture for a clutter angle of 0.5° and antenna to fence distance of 400 ft. Also included in the figure are curves for 10 and 14 foot high simple fences. The curves illustrate that although complex fences potentially can provide greater net clutter suppression than simple fences of the same height, simple fences provide sufficient suppression to meet the radar system requirements at the low aircraft elevation angles of interest.

Since complex fences require greater development effort compared to a simple fence and are more expensive to fabricate because of the non-uniform edge design, they are not recommended for use at Phan Rang.

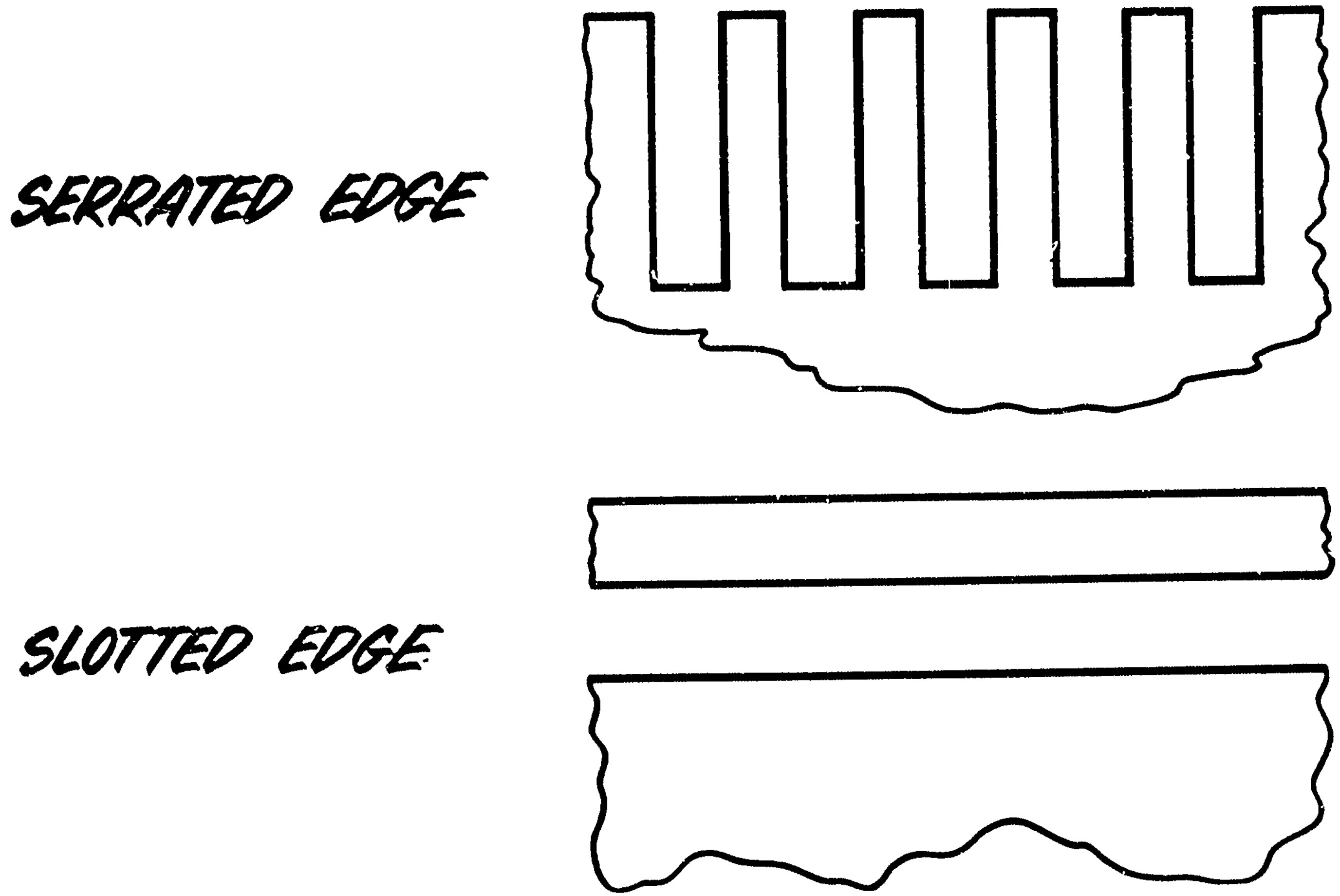


Figure 6-1. Serrated Edge and Slotted Edge Complex Fences

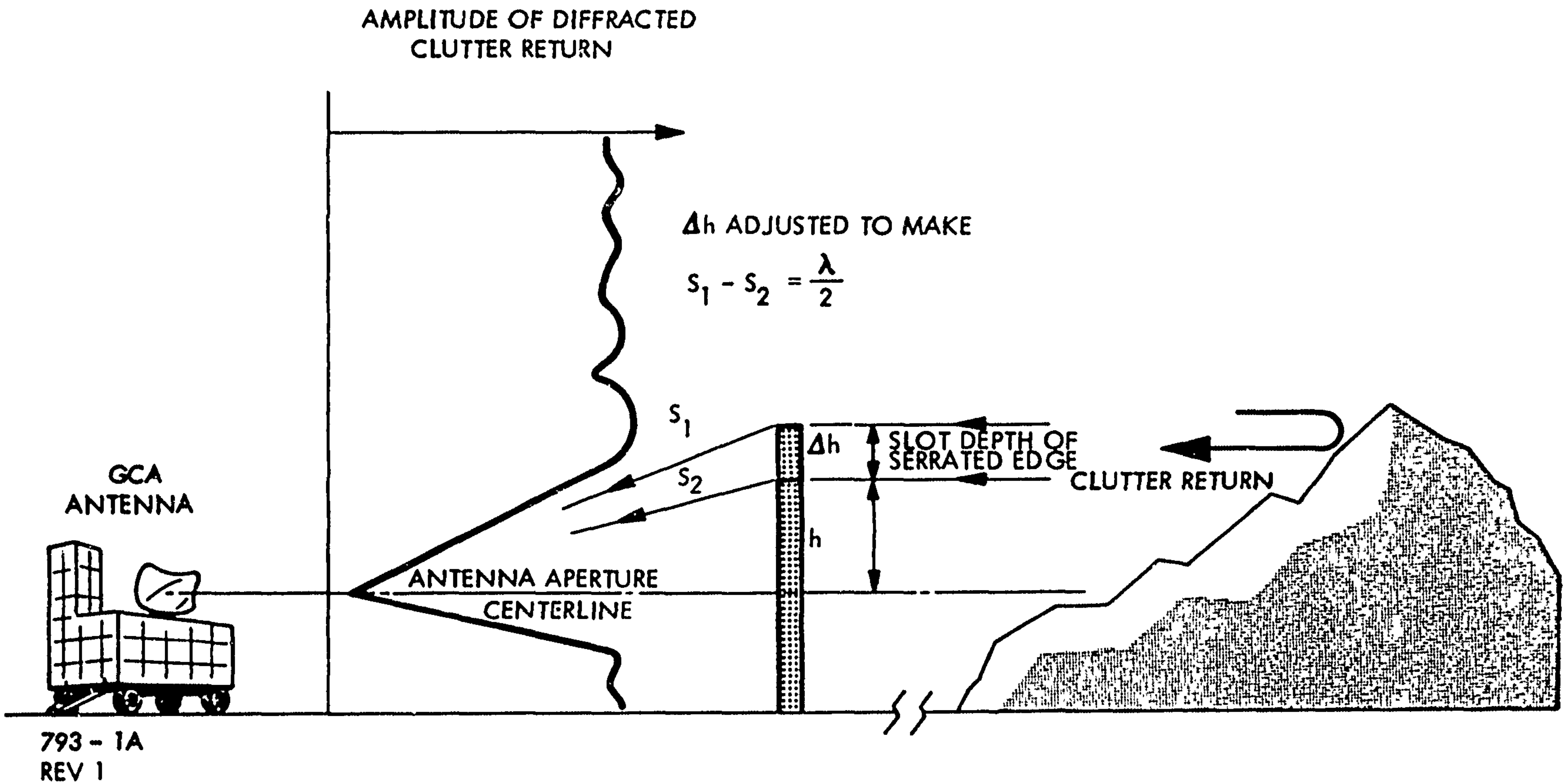


Figure 6-2. Principle of Operation of Serrated-Edge Complex Fence

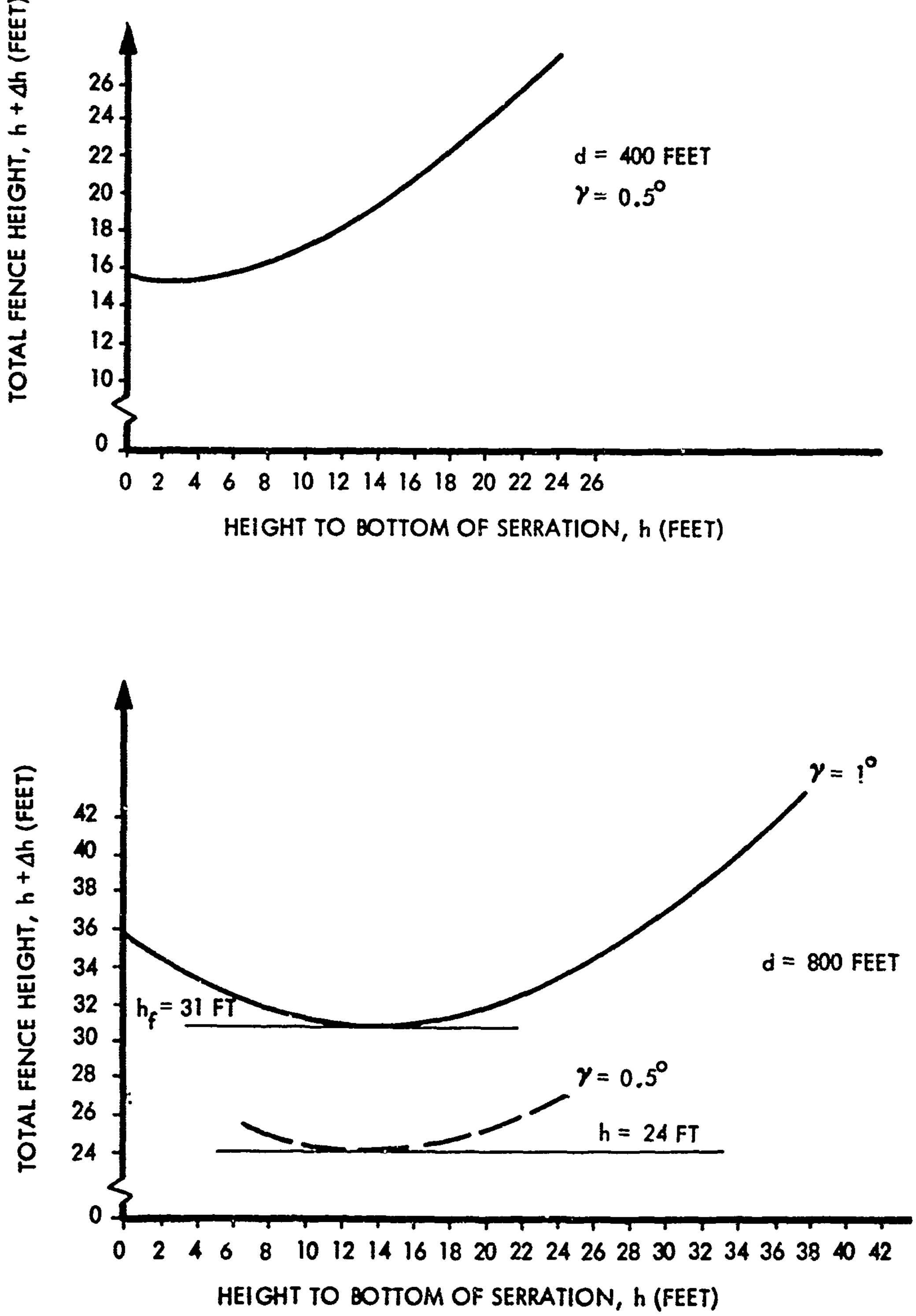


Figure 6-3. Complex Fence Height Versus Slot Location, (Serrated Edge Type) (Refer to Figure 6-2 for Fence Geometry)

793 - 3A
REV 1

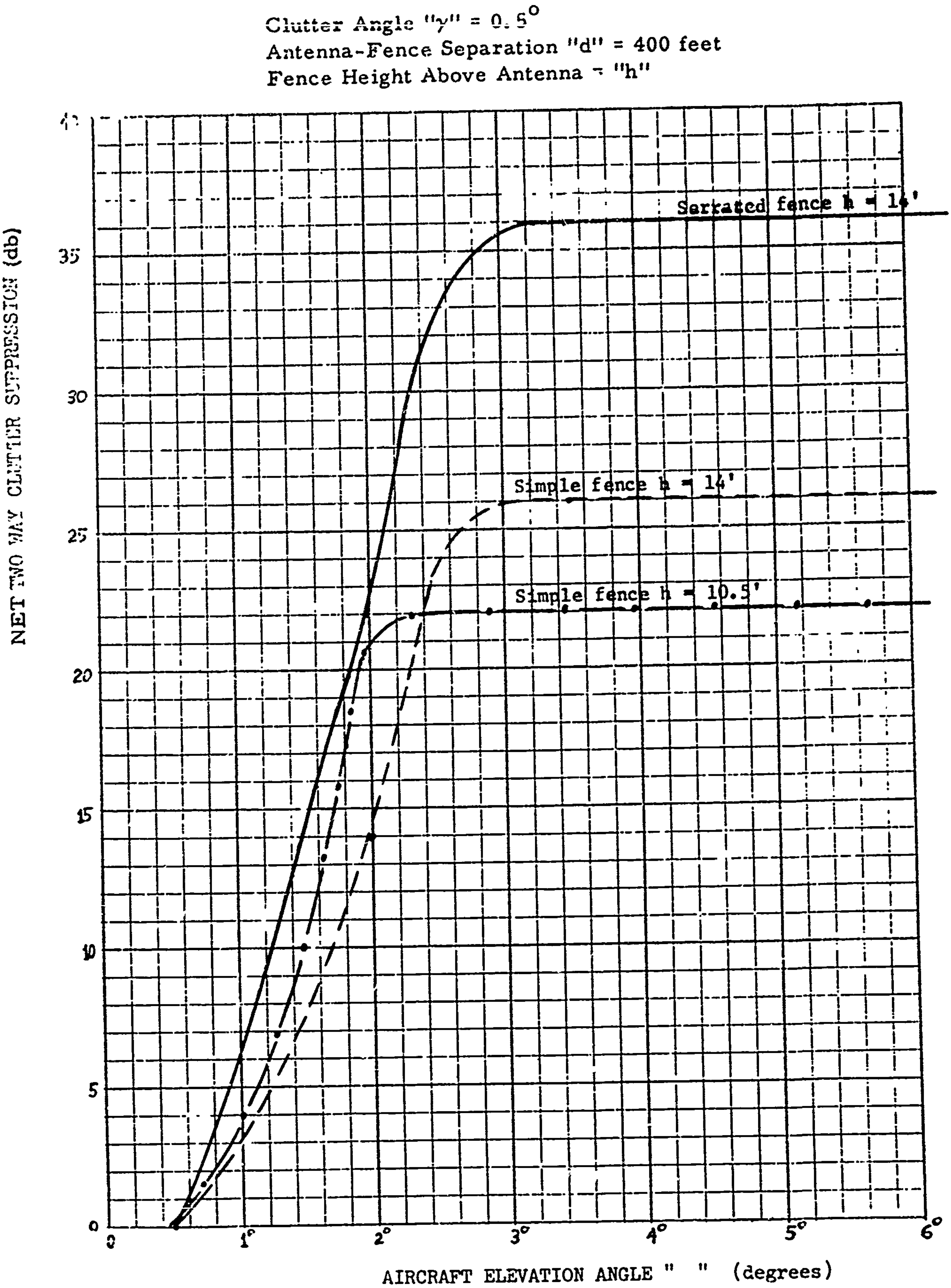


Figure 6-4. Comparison of Net Two-Way Clutter Suppression for Complex and Simple Fences

7. MULTIPLE FENCES

An alternative method of obtaining increased clutter suppression is to use multiple fences, i.e., two or more fences of different radii. This approach is illustrated in Figure 7-1, where a second fence has been added to provide double diffraction of the clutter return. Multiple fences are used to best advantage when the clutter return comes from elevation angles below the horizon, as is the case with ground reflections. For clutter returns above the horizon, as occurs at Phan Rang, the advantage of multiple fences over the single fence is small. This is particularly true for small angular separations between aircraft and clutter. A single fence, for example, will provide 12 db two-way clutter suppression if the antenna is located at the geometric shadow of the fence. Adding a second fence will increase the two-way clutter suppression by about 6 db. Each additional fence will add an even smaller contribution. The same 6 db increase in clutter suppression could be obtained at less cost with a single fence by increasing its height and/or locating it further from the radar. Multiple fences are therefore not recommended for use at Phan Rang or similar sites.

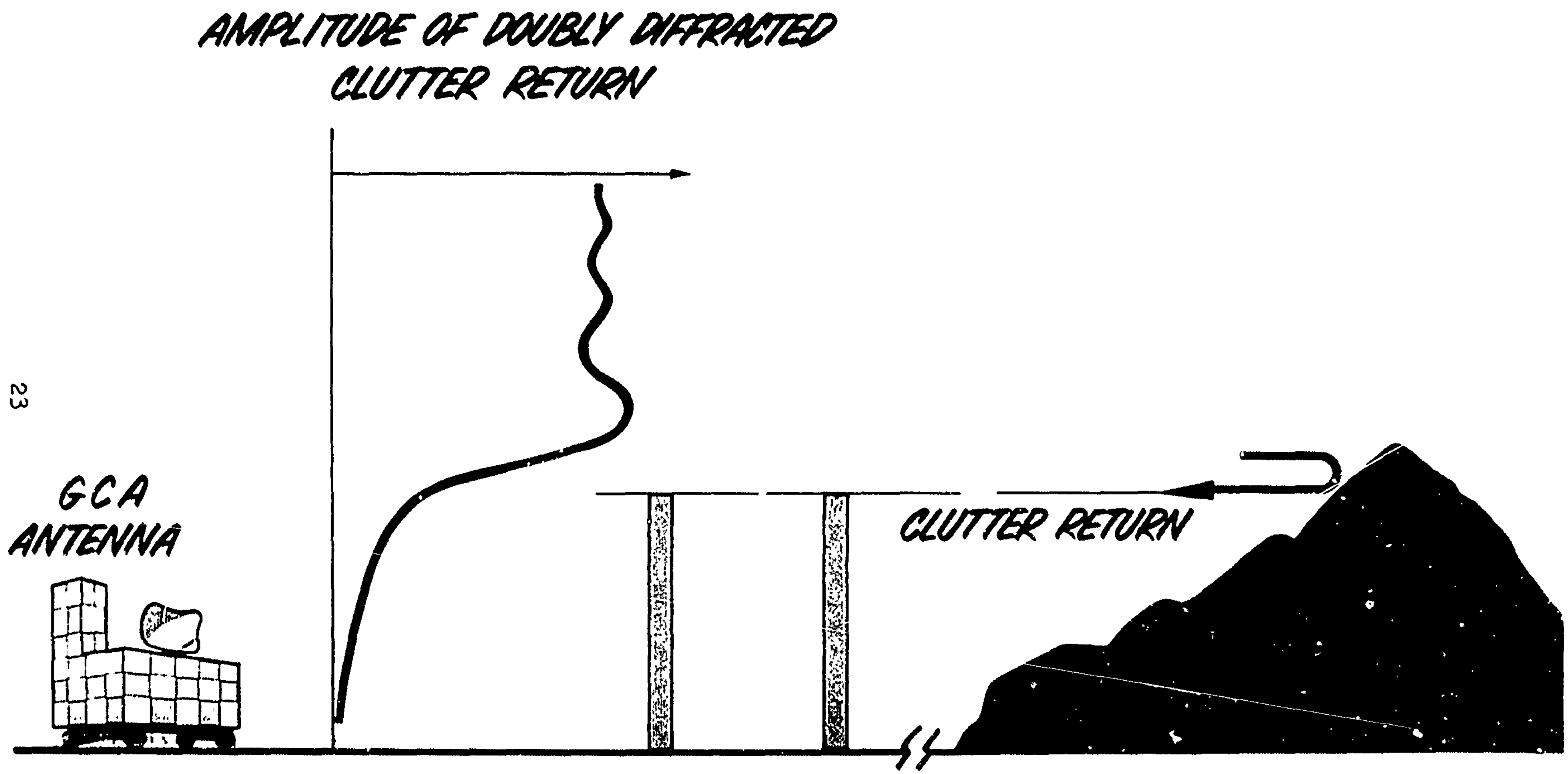


Figure 7-1. Principle of Operation of Multiple Fences.

8. FENCE SCREENING MATERIAL

The use of a fence as an effective ground clutter shield will be defeated if the power leakage through the fence is greater than the power diffracted over the top. The leakage clutter return path is shown in Figure 8-1. The wire-mesh screening material should be selected so as to provide at least 5 db more attenuation (two-way) at S-band than the required clutter suppression. At the same time the two-way X-band attenuation should be less than 1 db so that the fence will not interfere with the performance of the PAR. In Figure 8-2 the S-band attenuation through the fence is plotted as a function of wire spacing and wire diameter. The required attenuation is shown by the shaded area. In Figure 8-3 the X-band attenuation is plotted as a function of the S-band attenuation. Figures 8-2 and 8-3 illustrate that the above requirements cannot be met with a single sheet of screening material. To obtain the desired 25 db of S-band attenuation requires a screening material whose wire spacings will result in at least 6 db of attenuation at X-band.

This incompatibility can be overcome by using a double-mesh screen, as shown in Figure 8-4. By appropriate choice of the screen parameters the fence can be made to act as a band-pass filter rejecting the S-band and passing the X-band components. The attenuation values given were calculated for standard fence screening materials and are therefore typical of the electrical performance which could be expected of the completed fence.

The PAR is not required to scan in certain sectors at the Phan Rang site where ASR clutter suppression is desired. For these sectors the X-band attenuation will not be a factor and a single screen fence with close wire spacings may be a more appropriate alternative to the double-mesh screen fence.

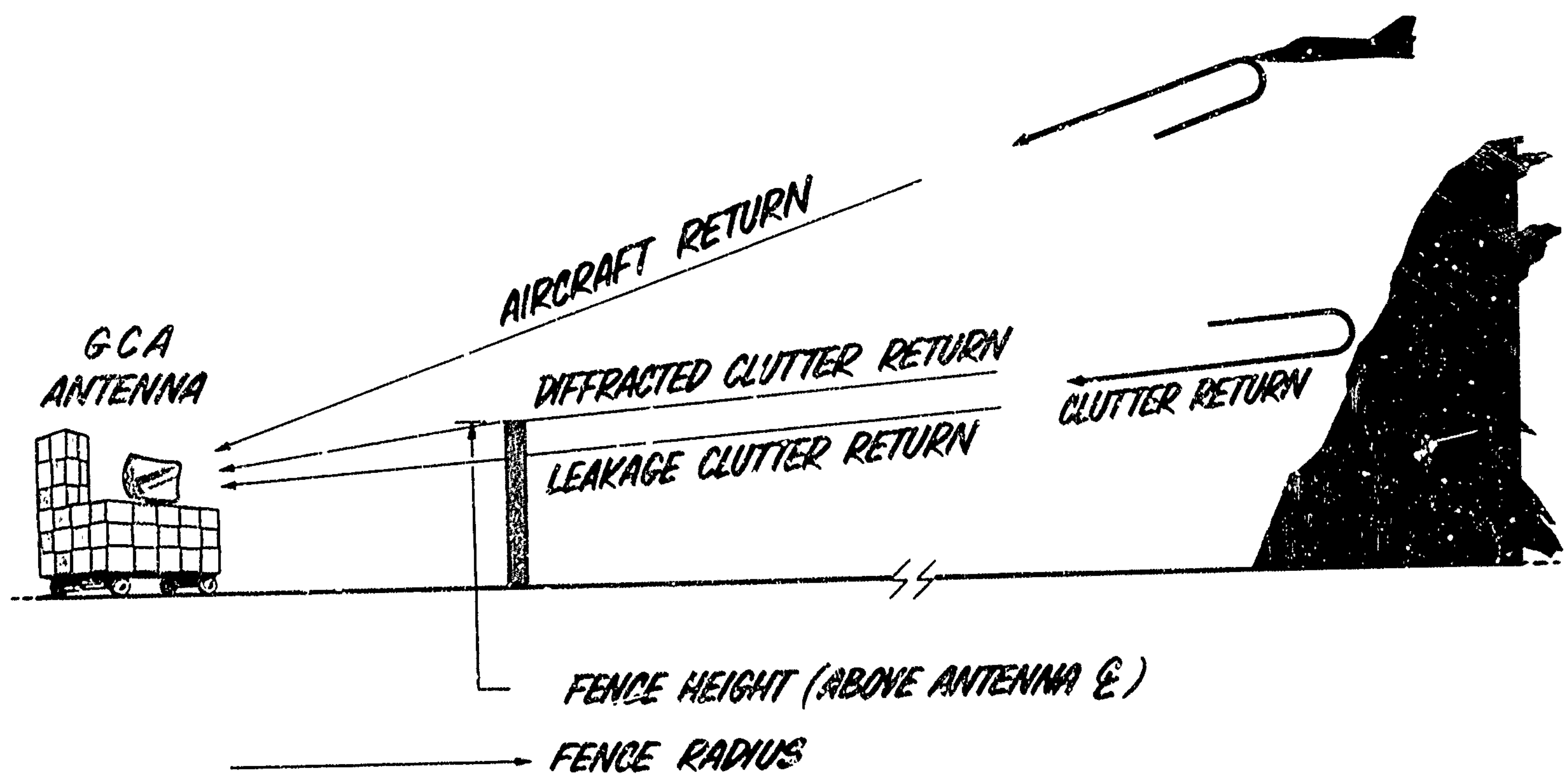


Figure 8-1. Leakage Path Through Fence

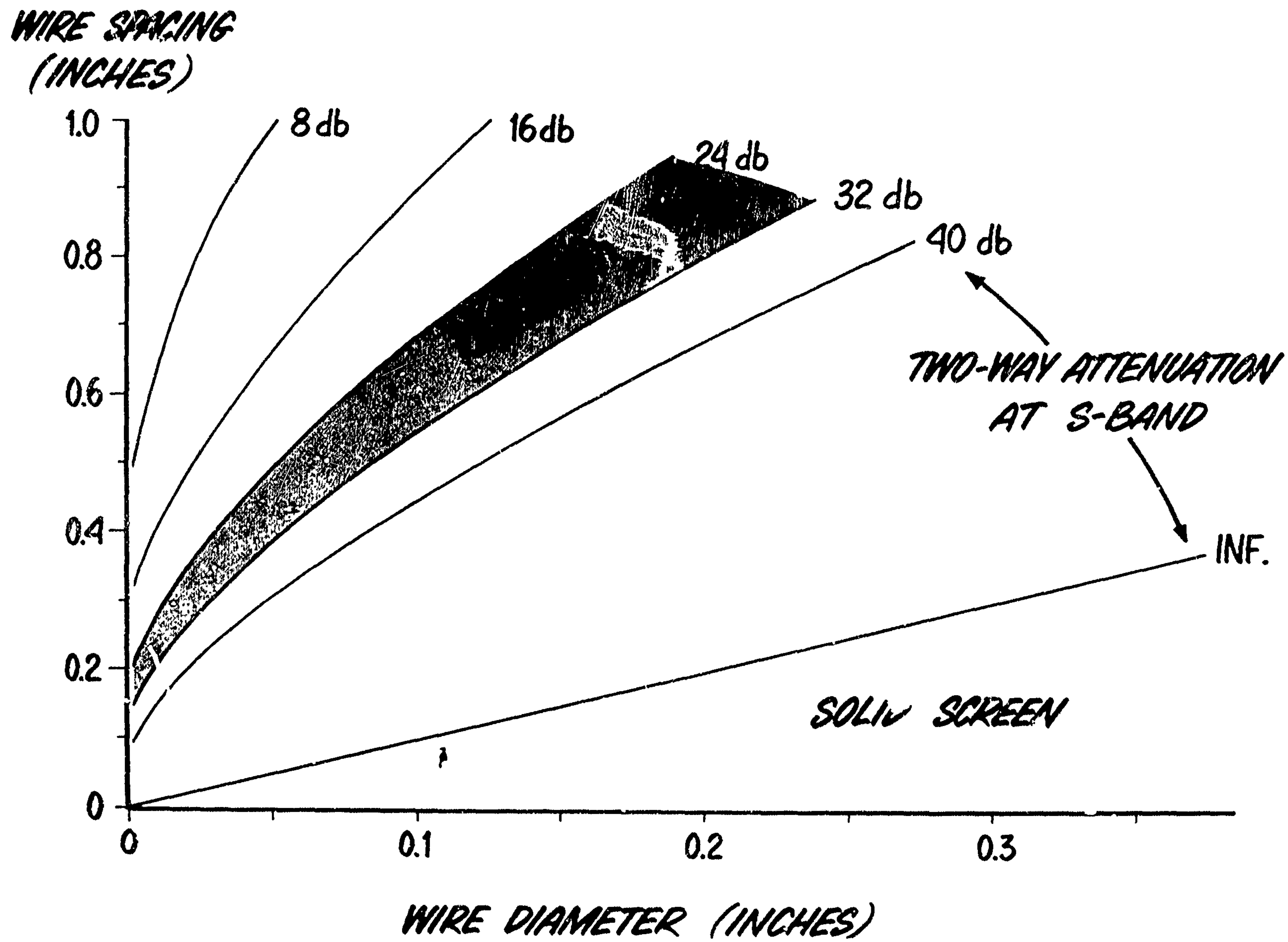


Figure 8-2. Screening Attenuation, S-Band.

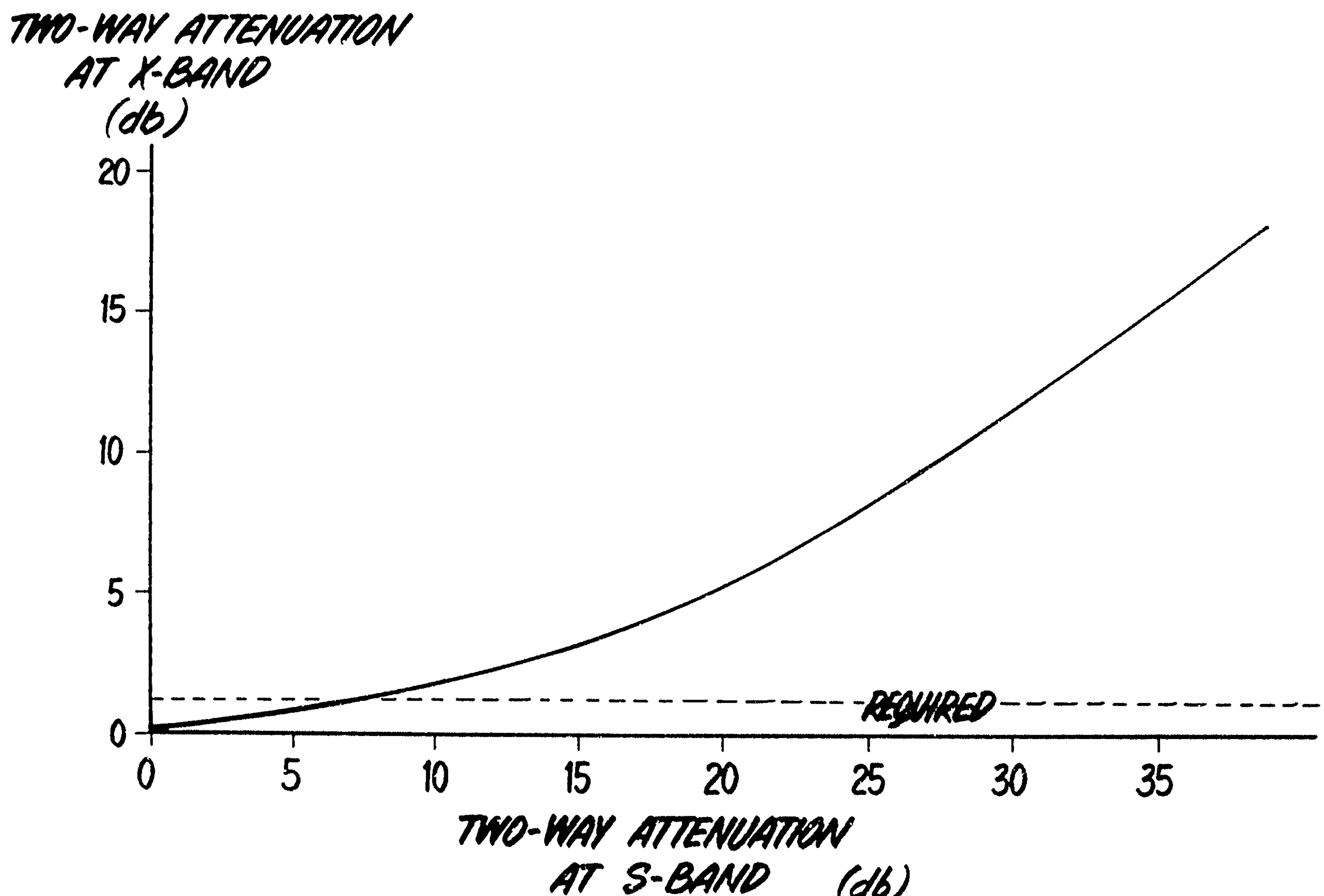
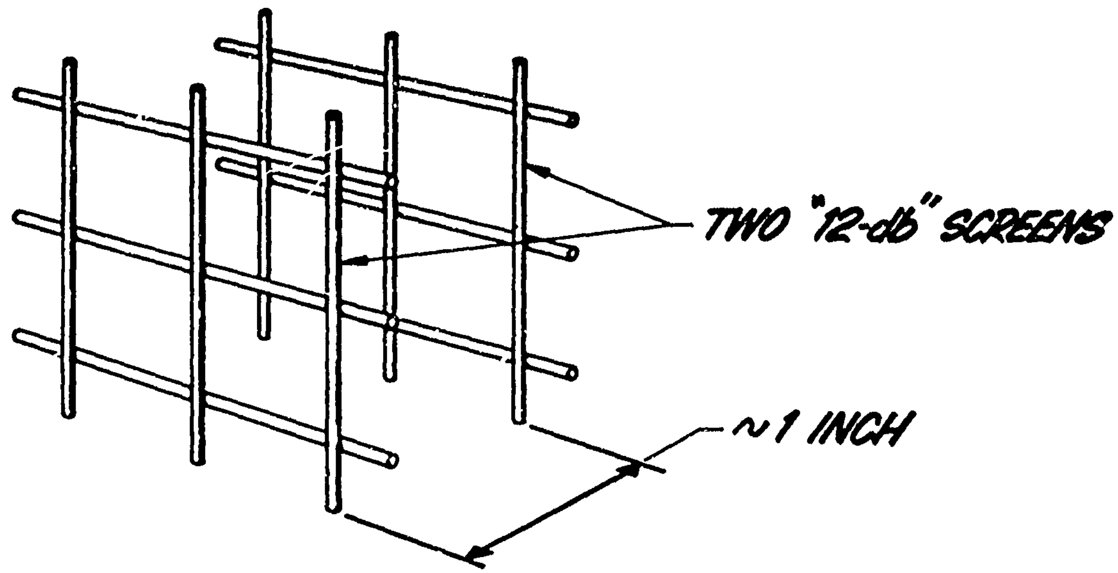


Figure 8-3. Screening Attenuation, S- Versus X-Band

EXAMPLE OF DOUBLE-MESH SCREEN



TWO-WAY ATTENUATION AT S-BAND........31 db

TWO-WAY ATTENUATION AT X-BAND..........0 db (THEORETICAL)

1 db (PRACTICAL)

Figure 8-4

23A0793

9. RECOMMENDED FENCES FOR PHAN RANG

The recommendations given here for fence construction at Phan Rang are based on studies of the clutter profile and aircraft flight path. The clutter profile, taken from contour maps of the Phan Rang area and on-location sitings, is shown in Figure 9-1. Elevation angles are to the peak of the highest obstructions within a 15 nautical mile radius of the radar. Also included is the prescribed aircraft radar approach flight path. The sectors requiring clutter suppression were determined on the basis of the clutter profile and clutter photographs (such as Figure 2-2). These sectors, shown in Figure 9-2 are from 163° to 191° and 211° to 230°.

The fence parameters which will provide the clutter suppression for the sectors of interest are determined from the relationship between the aircraft and clutter elevation angles and the physical constraints on fence construction imposed by the runway geometry and cost considerations. Referring to the clutter suppression curves in the Appendix, it is seen that for a clutter angle "γ" of 0.5° and aircraft elevation angle θ of $2\text{-}1/4^\circ$ the most economical fence for 20 db two-way net clutter suppression should rise 10 feet above the antenna and be located at a distance 400 feet from the antenna. By extending this fence over a 175-foot wide sector (from 208° to 233°), and using double-mesh screen construction, it will meet all the electrical performance requirements for the prescribed sector containing the runway.

The second sector requiring clutter suppression extends from $163^\circ$to 191°. In this sector the fence radius is limited to about 300 feet by proximity to the runway (see Figure 9-3). The electrical performance of the 300 foot radius fence can be obtained from the clutter suppression curves for d = 300 feet and $\gamma = 0.5^\circ$. These curves show that a 6-foot high fence providing 17 db of net two-way clutter suppression is the optimum choice for this

sector. By extending the fence over a 178-foot wide sector (from 160° to 194°), 17 db clutter suppression for the second sector can be achieved. A single screen can be used because the PAR does not scan in this sector, although the-double-mesh construction may still prove more economical.

The geometry of the recommended fence design with respect to the runway and radar at Phan Rang is illustrated in Figure 9-3. The fence parameters and calculated performance are summarized in Table 9-1.

TABLE 9-1

DIMENSIONS AND CALCULATED PERFORMANCE OF FENCES RECOMMENDED FOR PHAN RANG

Sector 208 to 233 Degrees	
Radius	400 feet
Height (Above Antenna)	10 feet
Length (25° Sector)	175 feet
Screening	3/4 in. square mesh, 0.054 dia. wire, double mesh configuration
Net Two-Way Clutter Reduction	20 db
Two-Way Attenuation of Screening	32 db (S) 1 db (X)
Sector 163 to 191 Degrees	
Radius	300 feet
Height (Above Antenna)	6 feet
Length (34° Sector)	178 feet
Screening	0.4 inch square mesh, 0.035 dia wire
Net Two-Way Clutter Reduction	17 db
Two-Way Attenuation of Screening	26 db (S) (X)

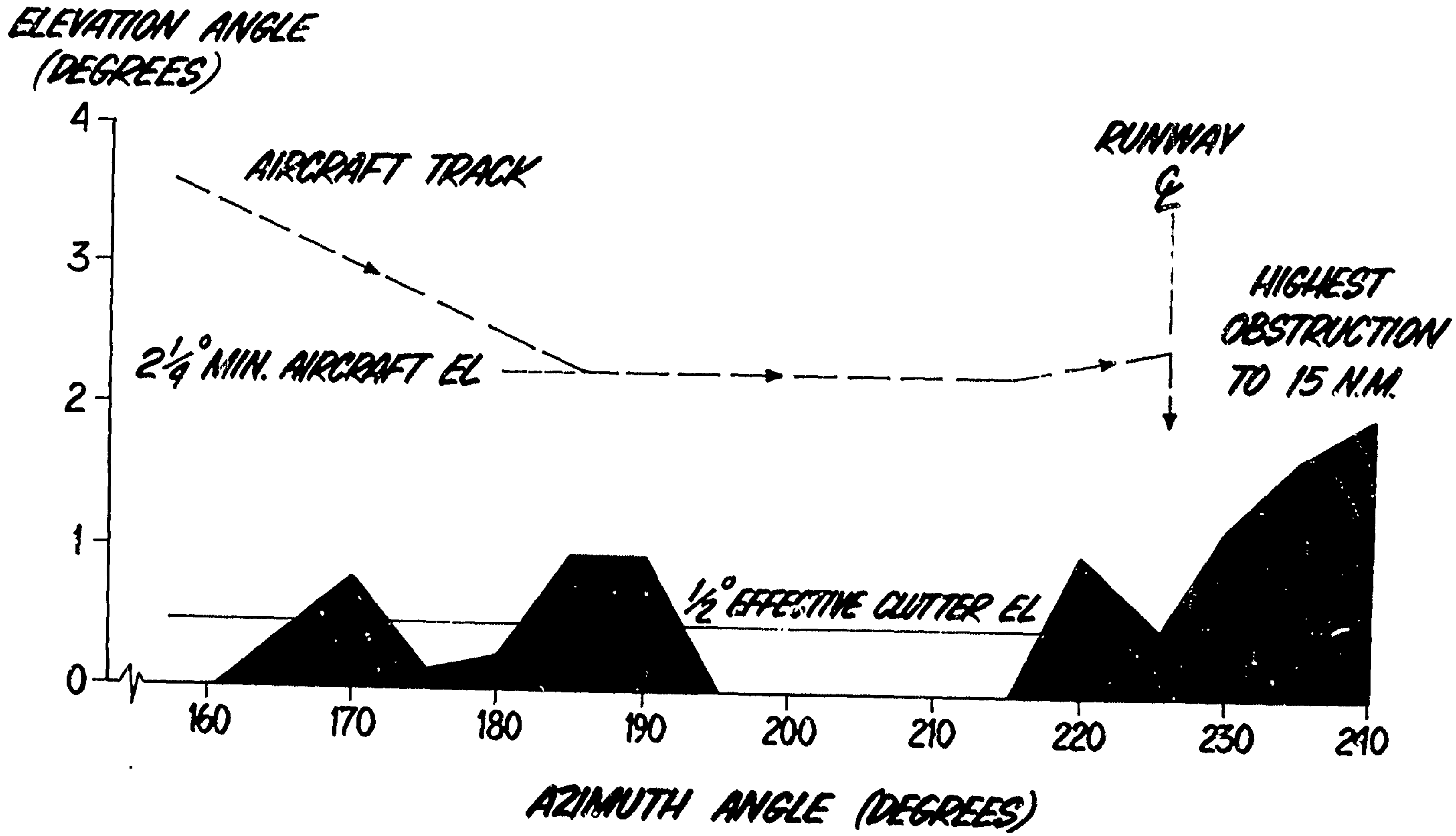


Figure 9-1. Clutter Profile of Phan Rang Area (from Radar), with Aircraft Track Superimposed

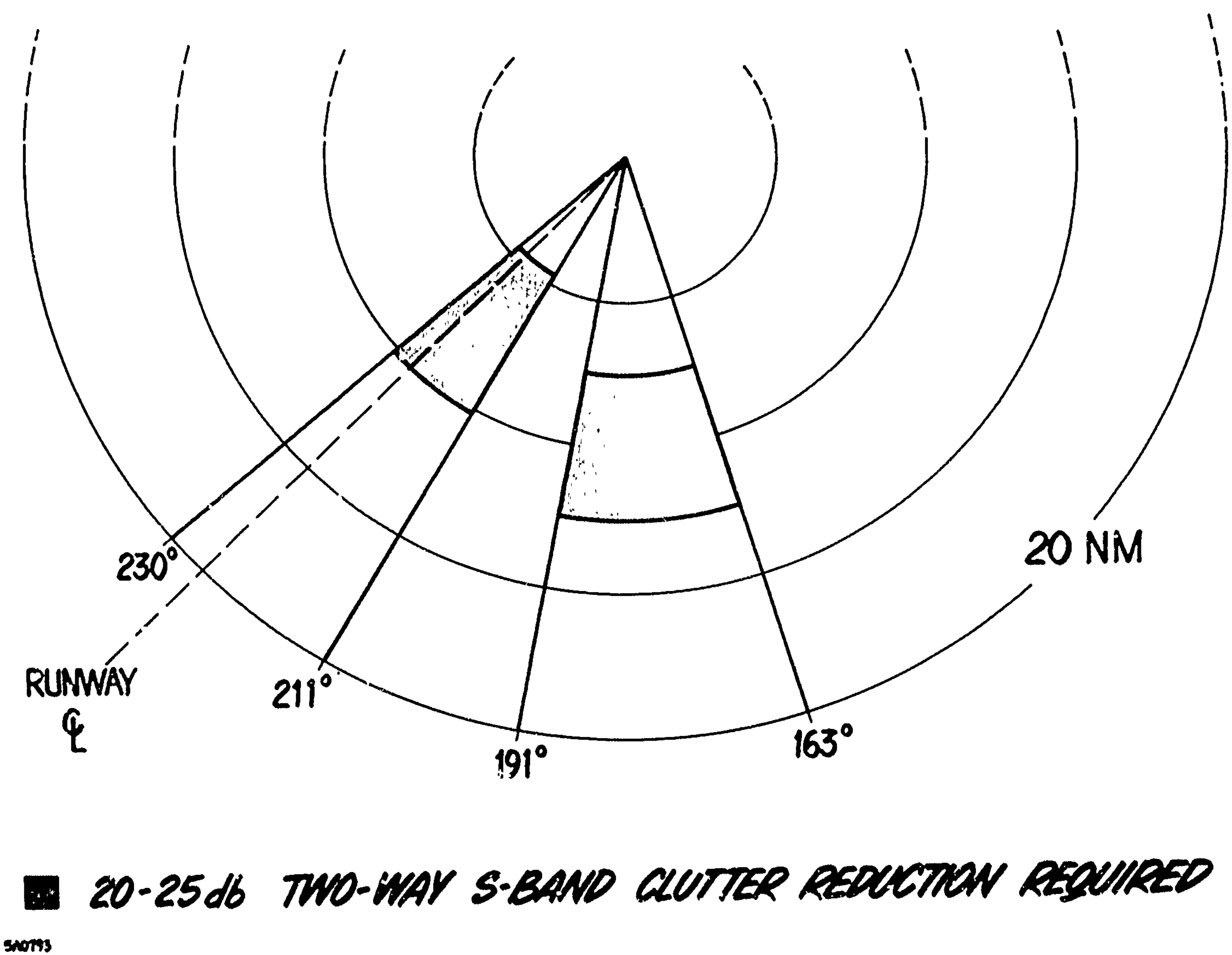
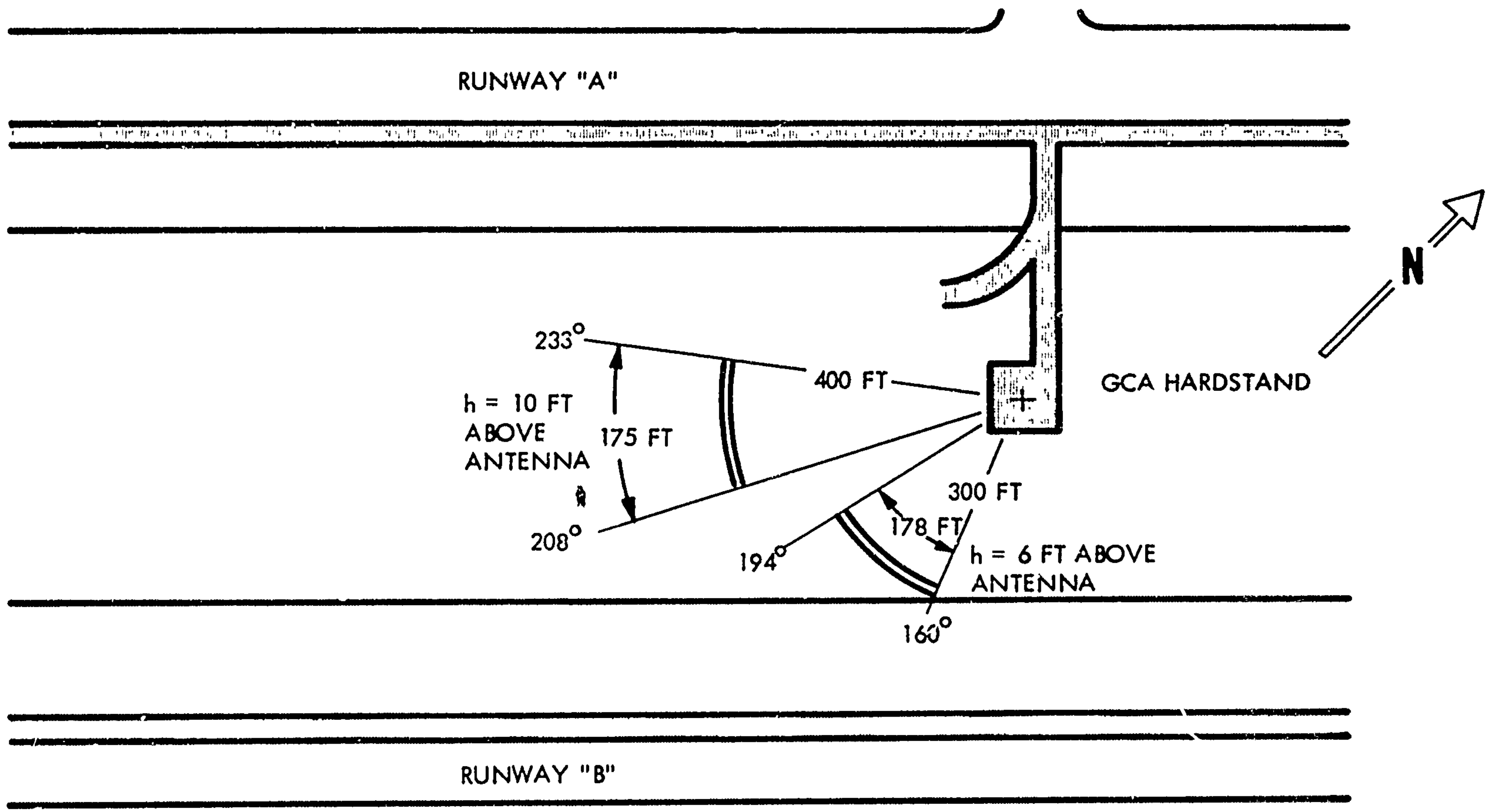


Figure 9-2. Sectors Requiring Clutter Reduction.



793 - 2A

Figure 9-3. Fence Locations for Phan Rang

10. COMPARISON WITH TEMPORARY FENCE

To alleviate the clutter problem, a temporary simple fence has been installed by the AF, using 1/2-inch square mesh (0.041 dia wires) screening. A section of the fence is shown in Figure 10-1). The approximate fence parameters are:

Radius = 166 feet

Height (above antenna) = 5 feet

Length (30° sector) = 88 feet

The net two-way clutter reduction for the fence has been calculated and is plotted in Figure 10-2. The performance, including screening attenuation, is summarized below:

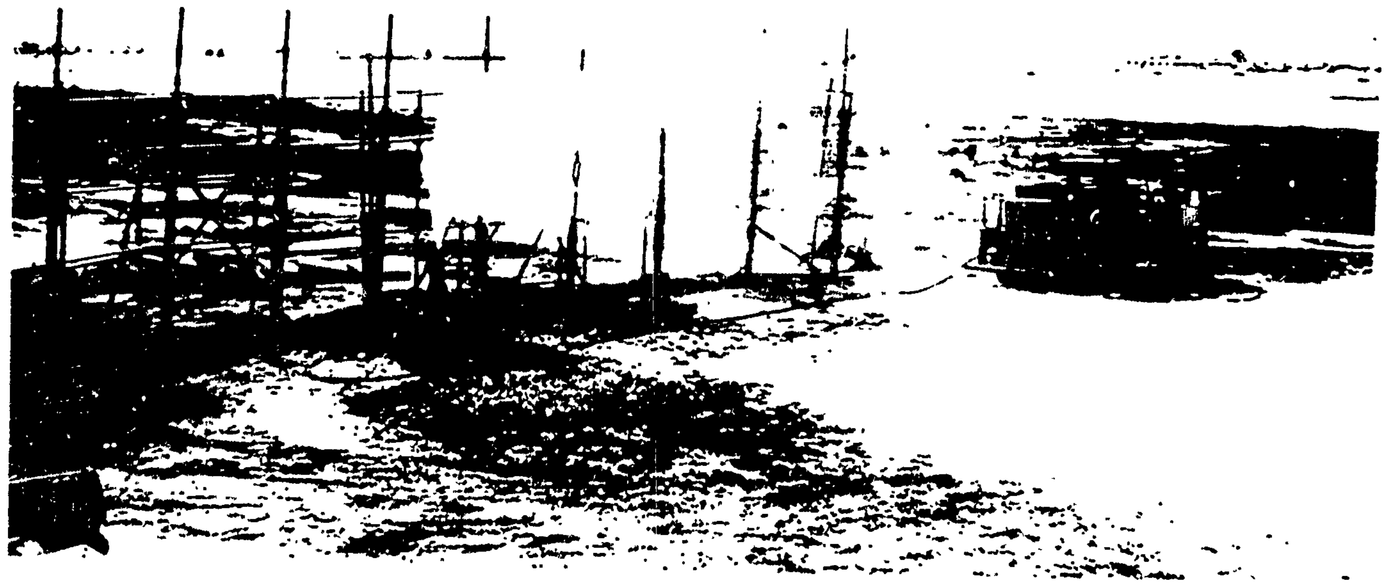
Two-way clutter reduction - 18.0 db

Net two-way clutter reduction - 9.4 db

Two-way attenuation of screening - 22.0 db (S)

6.3 db (X)

The net two-way clutter suppression of the existing fence is about 11 db below that of the fence recommended for installation at Phan Rang. Furthermore the 6.3 db of X-band attenuation can significantly decrease the range of the PAR, particularly in poor weather. The recommended fence, on the other hand, should have no more than 1 db X-band attenuation and will thus have little effect on the PAR.



28A0793

Figure 10-1. Temporary Fence at Phan Rang.

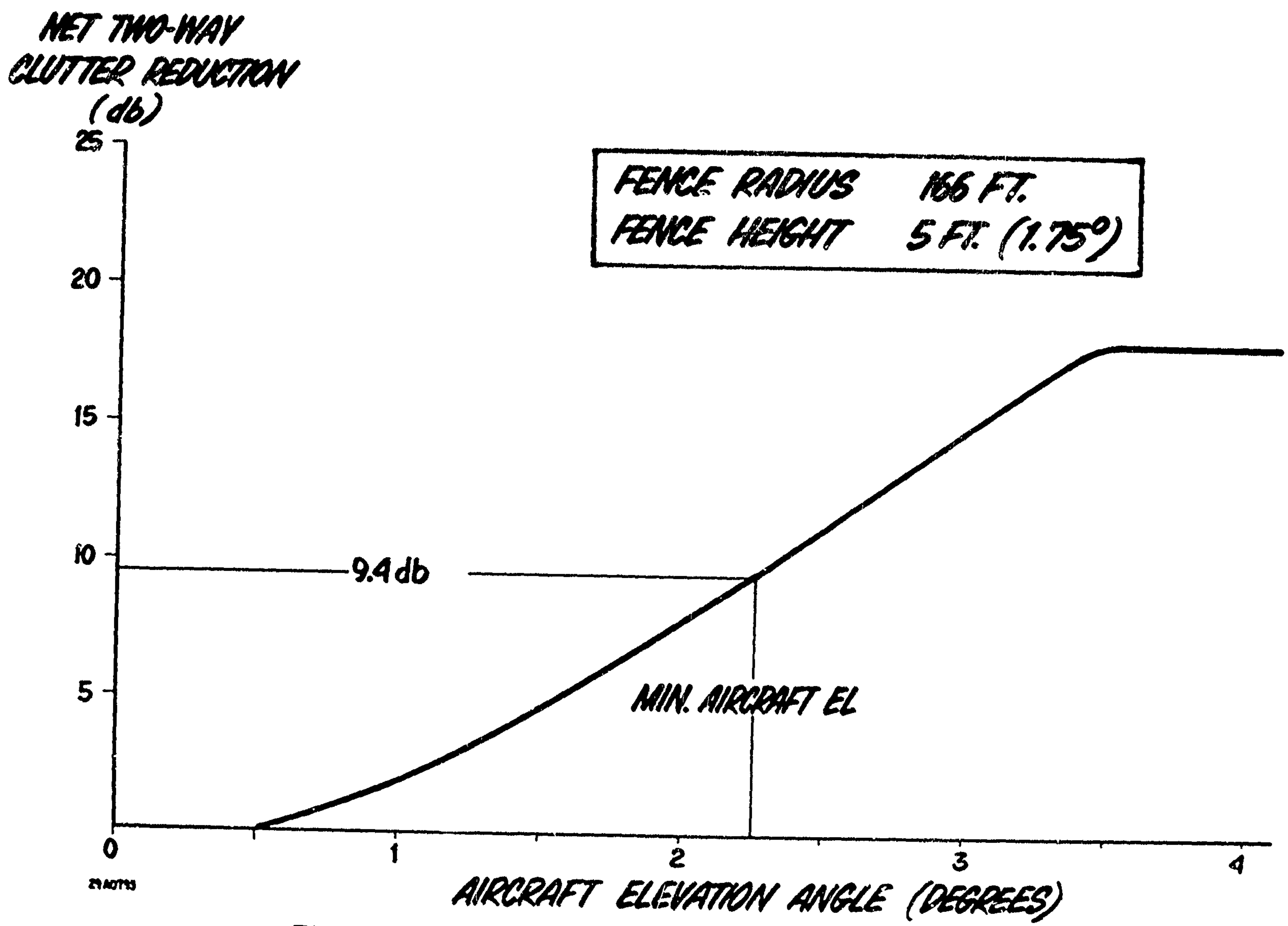


Figure 10-2. Performance of Temporary Phan Rang Fence

11. OTHER FENCE CONSIDERATIONS

11.1 Surveillance Approaches

In evaluating fence performance the criterion so far has been only that the suppression of clutter exceed that of the aircraft by at least 20 db. There is a limit, however, to the allowable aircraft suppression. The limit is that the aircraft must be discernible during final approach all the way to touchdown. In Figure 11-1, a plot of received power versus aircraft range for the ASR operating at Phan Rang shows that the theoretical maximum ranges for elevation angles of 0°, $1\text{-}1/2^{\circ}$, and 2.25° are 37 nm, 50 nm, and 58 nm, respectively (C-140). At these ranges the received power is equal to the MDS (Minimum Detectable Signal), and any additional reduction of signal would decrease the range.

The radar fence while suppressing unwanted clutter signals also suppresses any aircraft returns. For an antenna-fence separation of 400 ft. and a fence height above the antenna of 10 ft., the aircraft signal strength is down 12 db at an aircraft elevation angle of 1.5° (line-of-sight). At an elevation angle of 2.5° the aircraft signal is at free-space strength. At angles below 1.5° the signal strength decreases to -25 db at 0°. Under these conditions the theoretical maximum ranges are 9.0 nm, 26 nm, and 55 nm at 0°, 1.5°, and 2.25°, respectively (see Figure 11-1). There is then a significant decrease in range performance. This reduction in range, however, is not great enough to affect the normal operation of the radar set in the sector of interest. Therefore, an aircraft should be detectable throughout a surveillance approach.

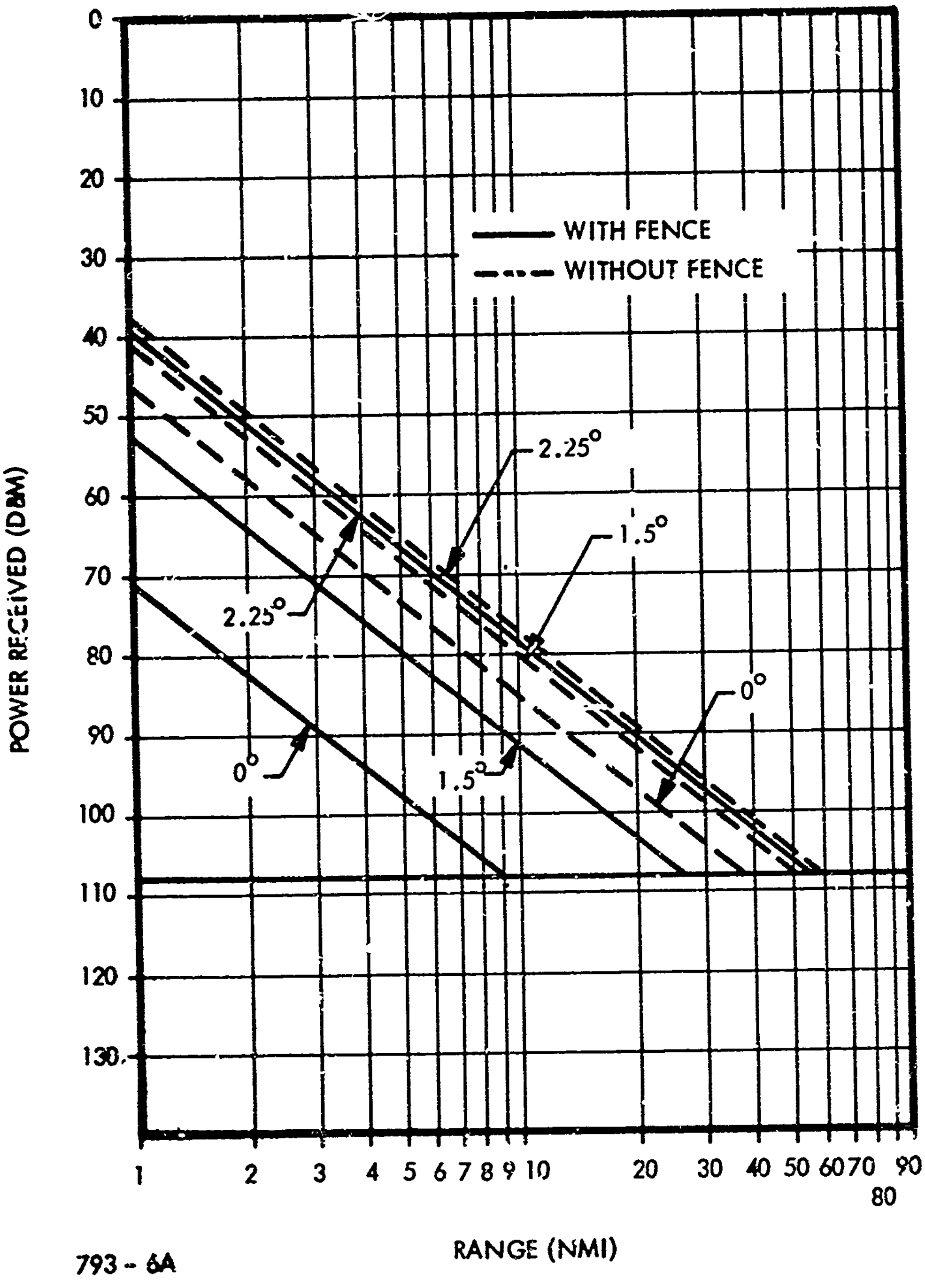


Figure 11-1. Received Power Versus Aircraft Range

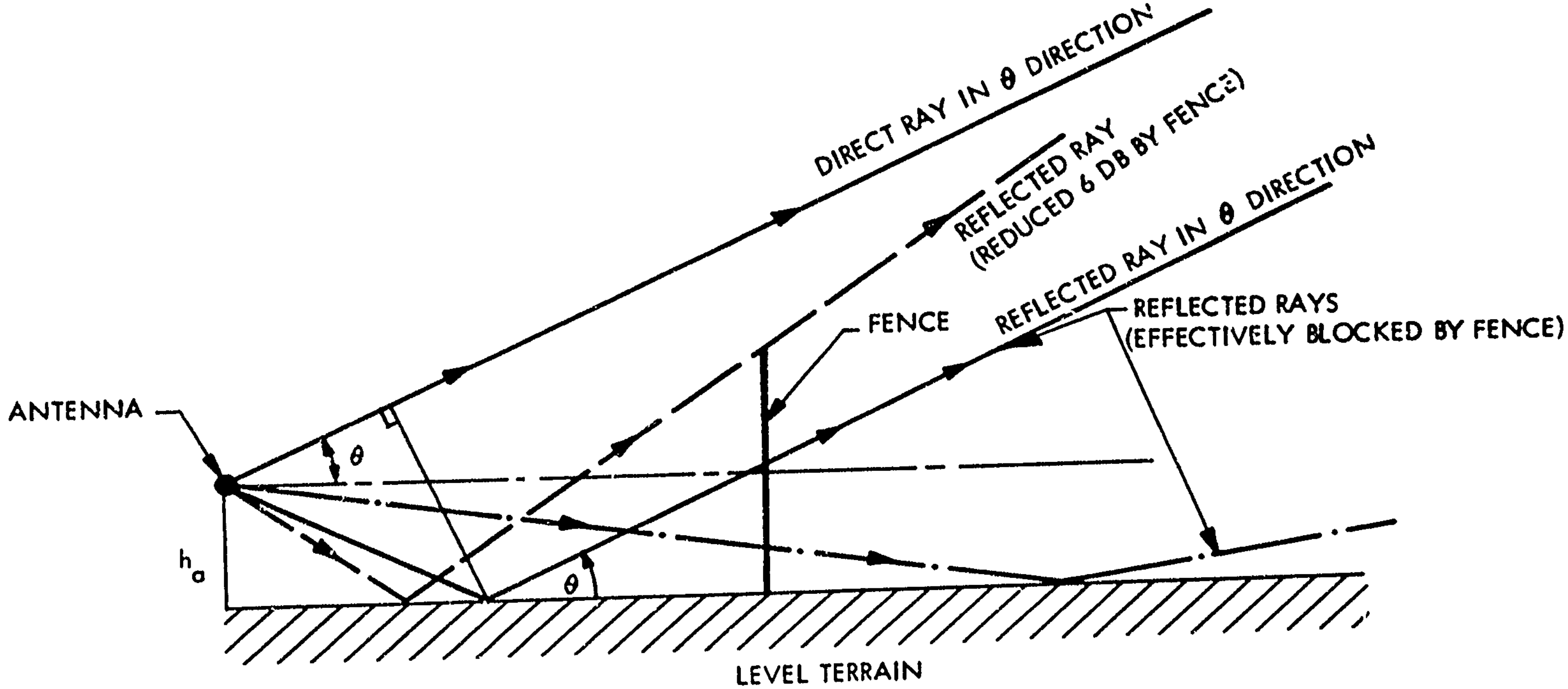
11.2 Direct Reflection

To eliminate the direct reflection of energy back into the antenna the fence will be tilted about 5 degrees from the vertical. A forward tilt (towards the antenna) will be used so as to reflect the energy downward thus minimize the possibility of ambiguous high-elevation aircraft returns. The small tilt angle will have a negligible effect on the clutter suppression of the fence.

11.3 Ground Reflections

Ground reflections in the direction of the main radiation of the antenna can destructively interfere with it and cause deep minima or nulls in the coverage pattern. The precise location and magnitude of these nulls is extremely difficult to predict because of the large number of factors which must be considered. These include the antenna radiation pattern (power and phase), frequency, polarization, grazing angles, terrain surface roughness, soil type, moisture content, vegetation growth, weather, and season.

A radar fence can help minimize these nulls by intercepting the ground directed energy. This is illustrated in Figure 11-2 for the simplified case of a smooth and level terrain. The ground reflected rays which are shown blocked or reduced at least 6 db by the fence would otherwise be directed in the same direction as the main radiation pattern. The pattern nulls are caused when phase differences due to path lengths and ground reflections are such that the direct and reflected energy tend to cancel. For smooth and level terrain, and grazing incidence, the reflection coefficient = -1, and cancellations occur whenever the path length difference, ΔS, between the direct and reflected energy is an integral number of wavelengths, i.e., $\Delta S = n \lambda$. The relationship between the antenna



INTERFERENCE OCCURS WHENEVER DIFFERENCE IN PATH LENGHTS BETWEEN DIRECT AND REFLECTED RAYS, ΔS, IS AN INTEGRAL NUMBER OF WAVELENGHTS, I.E. $\Delta S = n\lambda$.

793 - 8A
REV 1

Figure 11-2. Ground Reflections--Interference of Direct & Reflected Rays

height and null angles can be obtained from the geometry of Figure 11-2, and is $\Delta S = 2 h_a \sin \theta = n \lambda$.

The nulls appear whenever $\sin \theta = \frac{n \lambda}{2h_a}$. For an antenna height h_a above ground of 14 feet and a frequency of 2.8 GHz (λ = 0.351 feet), the nulls will be spaced at about 0.7 degrees intervals at the lower elevation angles. The portion of the ground which contributes to a null in the θ direction is centered about a distance $d = h_a \cot \theta$ from the radar. For the terrain assumptions of the preceding paragraph, the improvement in the radar coverage due to the reduction of ground reflections can be estimated by considering the antenna-terrain geometry and the radiation pattern. The same type of improvement will result from the installation of the recommended fences (Section 9) at Phan Rang although its magnitude is difficult to estimate because of the site complexity.

11.4 Leakage Under Fence

The rf leakage under the fence should be suppressed by at least 25 db if the fence is to provide a clutter rejection of 20 db. The leakage requirements will be met by placing the bottom of the fence slightly beneath the surface of the ground on as close to ground level as practical. The proposed fence construction is shown in Figure 12-1.

11.5 X-Band Rain Attenuation

Water spray tests on the temporary fence at Phan Rang showed that there is very little X-band attenuation through the fence due to the accumulation of water droplets on the fence screening. The double-mesh design of the recommended fence (Figure 8-4) will allow the use of an even greater mesh size than is used in the temporary fence, thus assuring that the X-band ran attenuation through the fence will not be a problem.

11.6 X-Band Tracking Error

The PAR antenna will experience a small elevation tracking error of extremely short duration when the aircraft elevation angle coincides with the top of the fence. This is due to a slight beam tilt resulting from the portion of the beam looking through the fence undergoing a differential phase shift compared to the portion looking over the fence. The magnitude of the beam tilt can be approximated by taking the ratio of the longitudinal beam displacement, caused by the differential phase shift, to the vertical coverage (elevation beamwidth) of the beam at the fence. The phase differential for the proposed Phan Rang fence was estimated to be about 60° or 0.2 inches at X-band. The vertical coverage of the beam at the fence is difficult to determine precisely because the fence is in the near-zone field of the PAR antenna. In similar cases, however, where the field has been worked out in detail, it has been found that the near-zone field is determined essentially by geometrical propagation along the aperture-ray system. For the PAR antenna, the geometrically propagated field will have a vertical coverage comparable to the length of the antenna aperture in the elevation plane, or about 14 feet. The beam tilt or tracking error corresponding to the ratio of 0.2 inches to 168 inches (14 feet) is less than 0.1 degree and will not seriously affect the tracking capabilities of the system.

12. FENCE-CONSTRUCTION TECHNIQUES

The main requirements that ITT Gilfillan considered in selecting the type of fence construction to be recommended for use at Phan Rang and other sites were:

a. Universality - Unitized modular construction should be used so that once the requirements for a given site were determined an appropriate fence could be constructed rapidly from readily available components.

b. Mobility - The size of the modular components should be such that they can easily be transported and stored.

c. Mechanical Performance - The fence must be able to meet the environmental specifications, yet collapse easily so as not to damage an aircraft upon impact.

d. Cost - Standard screening material should be used so as to keep the fence cost to a minimum.

The recommended type of fence construction is shown in Figures 12-1 and 12-2. The fence "modules" consist of double-mesh screening to meet the S- and X-band electrical requirements. Once the supporting foundation is laid the fence can be fabricated rapidly by attaching the modules to the vertical poles, made of fiberglass or other frangible material. Further refinements to the fence construction will be made during Phase II of this program.

13. CONCLUSIONS AND RECOMMENDATIONS

The "simple" rf fence is the most effective technique for providing a 20 db increase in S-band clutter rejection at the Phan Rang GCA radar site within a short time scale. This conclusion is based on the following findings contained in this report:

a. Antenna redesign is desirable, but it is not a short term solution to the clutter problem.

b. Complex fences can provide greater net clutter suppression than simple fences of the same height but the latter provide sufficient suppression to meet the radar system requirements at the aircraft elevation angles of interest.

c. Simple fences (including double mesh) require minimum development effort compared to the complex fence, and are cheaper to fabricate.

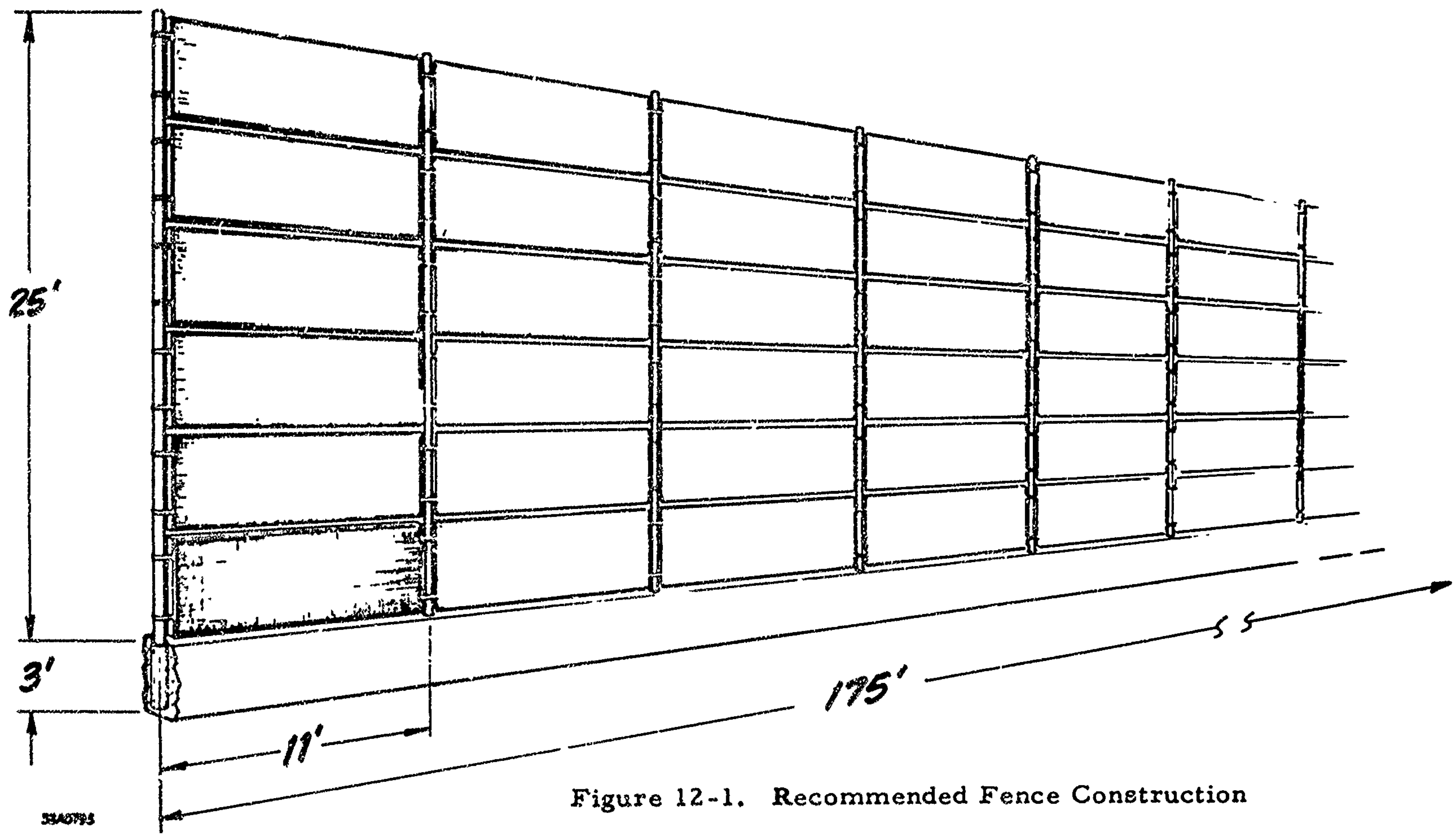


Figure 12-1. Recommended Fence Construction

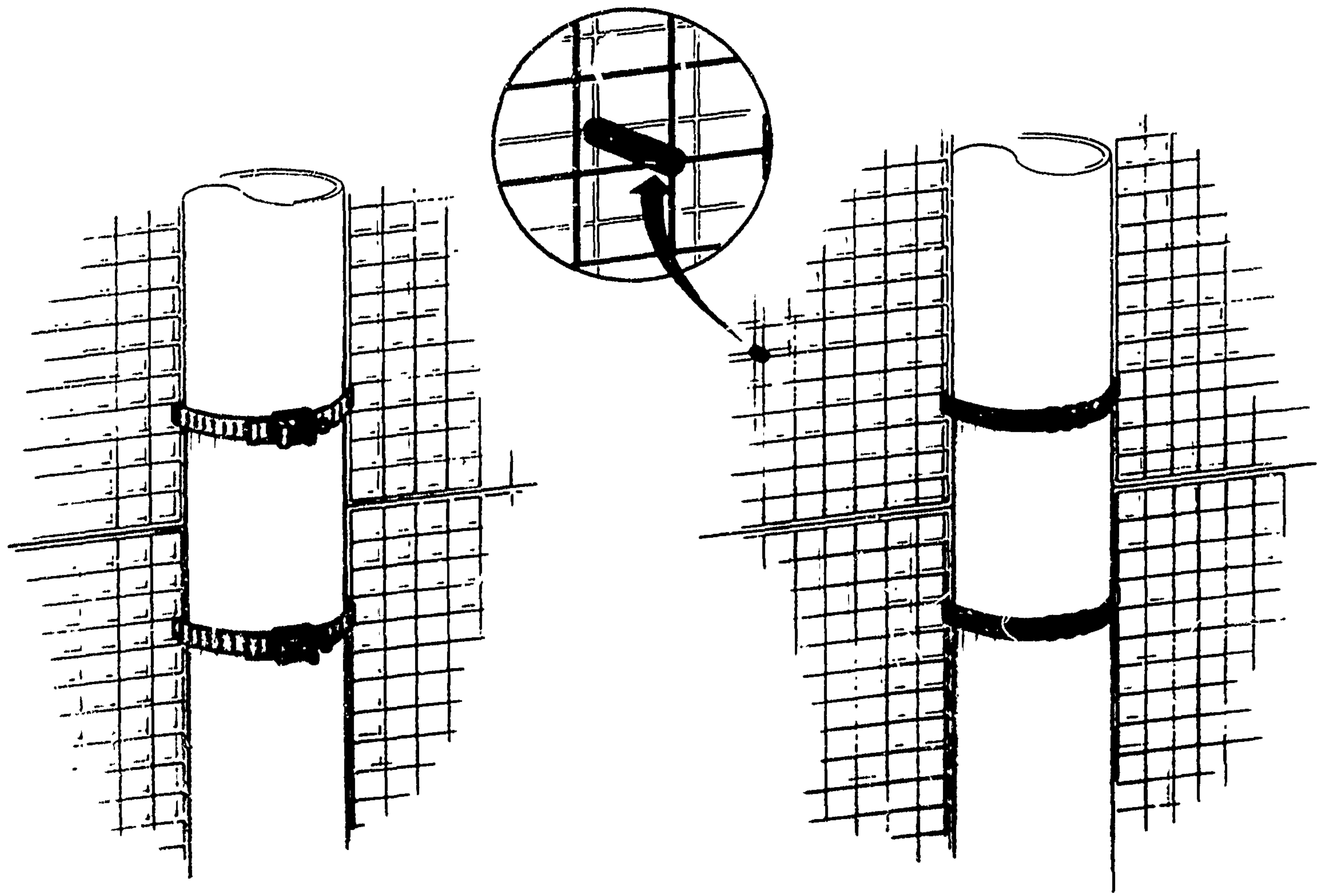


Figure 12-2. Detailed View of Fence Construction.

d. Multiple fences (simple or complex) provide a small increase in clutter rejection but at a far greater cost in fence material and construction time.

e. In addition to providing clutter rejection, fences improve the radar coverage by reducing ground reflections that cause nulls in the radiation pattern.

On the basis of these findings it is recommended that Phases II and III--fabrication and installation of the fence, and on-site testing of the radar with the fence installed--be initiated as soon as possible.

BIBLIOGRAPHY

1. J. E. Becker and J. C. Sureau, "Control of radar site environment by use of fences," IEEE Trans. and Propagation, Vol. AP-14, pp. 768-773, November 1966.

2. J. E. Becker, "Design study for AMRAD anti-clutter fence," Wheeler Labs. Rept. 1233, to M. I. T. Lincoln Lab., Lexington, Mass., July 22, 1964, Listed with DDC, AD-455-973.

3. J. Ruze, F. I. Sheftman, and D. A. Cahlander, "Radar ground-clutter shields," Proc. IEEE, Vol. 54, pp. 1171-1183, September 1966.

4. M. Born and E. Wolf, Principles of Optics. New York: Pergamon, 1959, ch. 8 (Fresnel Diffraction).

APPENDIX

NET TWO-WAY CLUTTER SUPPRESSION CURVES

The curves in this Appendix show the Net Two-Way Clutter Suppression vs. Aircraft Elevation Angle for simple fences. The clutter angle values of 0, 0.5, 1.0, and 1.5 degrees, and antenna-to-fence distances of 100, 200, 300, 400, 800 and 1600 feet were chosen so as to be applicable to Phan Rang and similar sites. The Net Two-Way Clutter Suppression, defined as the ratio of the Two-Way Clutter Suppression to the Two-Way Target Suppression were obtained from equation (5.3) for the case of the AN/MPN-( ) antenna operating at a frequency of 2.8 GHz and with beam peak pointing at +6 degrees in elevation.

To apply the curves to a fence site it is first necessary to determine the range of angles for the clutter return from the surrounding area. These are obtained from clutter profile maps of the site area or by making elevation sitings of the surrounding terrain. An average value for the clutter angle can be taken for each azimuth sector where clutter return is a problem. By consulting the appropriate set of curves (i.e., γ = 0, 0.5, 1.0 or 1.5 degrees) in the Appendix a fence with suitable clutter suppression performance at the aircraft elevation angles of interest can be selected. The required suppression is determined from system studies and on-side radar observations.

At the higher elevation angles there is no target suppression and the net clutter suppression curves level at their maximum value. The target suppression for any of the lower aircraft elevation angles can therefore be determined by subtracting the net clutter suppression at the corresponding point on the curve from the maximum value.

Use of the curves in selecting suitable fences for the Phan Rang site is illustrated in Section 9.

FIGURE A-1 NET TWO WAY CLUTTER SUPPRESSION FOR SIMPLE FENCES

CLUTTER ANGLE "γ" = 0°

ANTENNA - FENCE SEPARATION "d" = 100 FEET

FENCE HEIGHT ABOVE ANTENNA = "h"

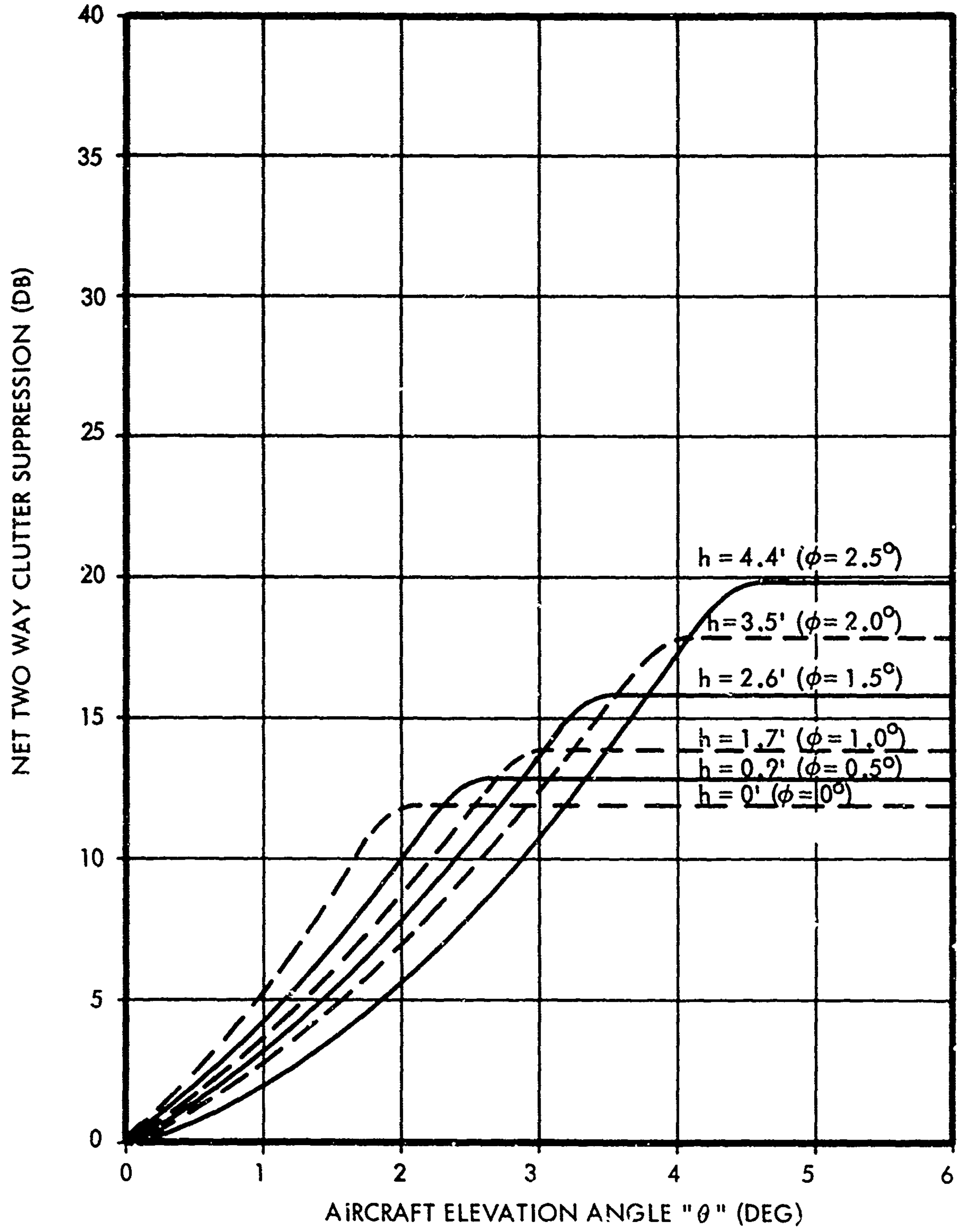


FIGURE A-2 NET TWO WAY CLUTTER SUPPRESSION FOR SIMPLE FENCES

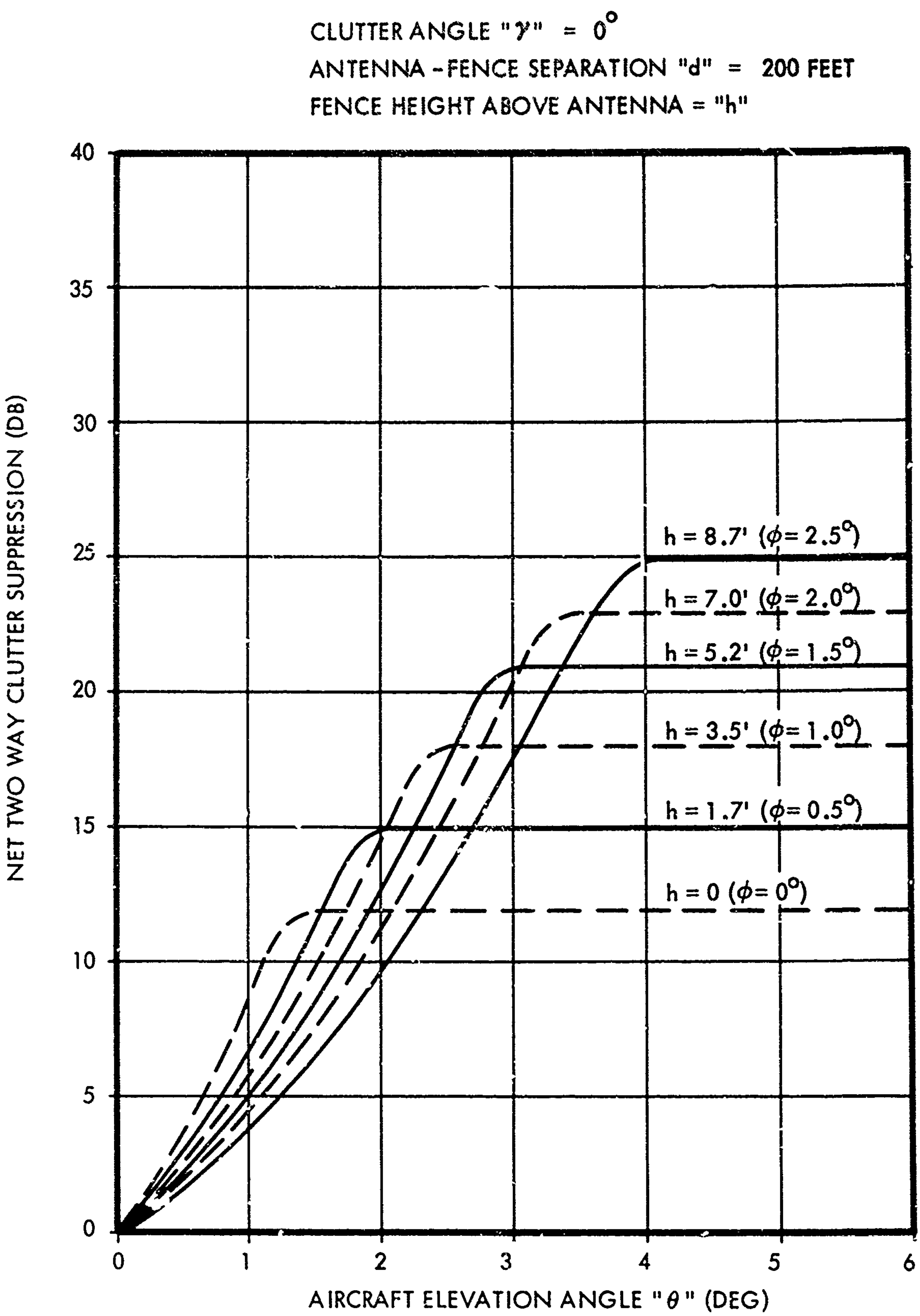


FIGURE A-3 NET TWO WAY CLUTTER SUPPRESSION FOR SIMPLE FENCES

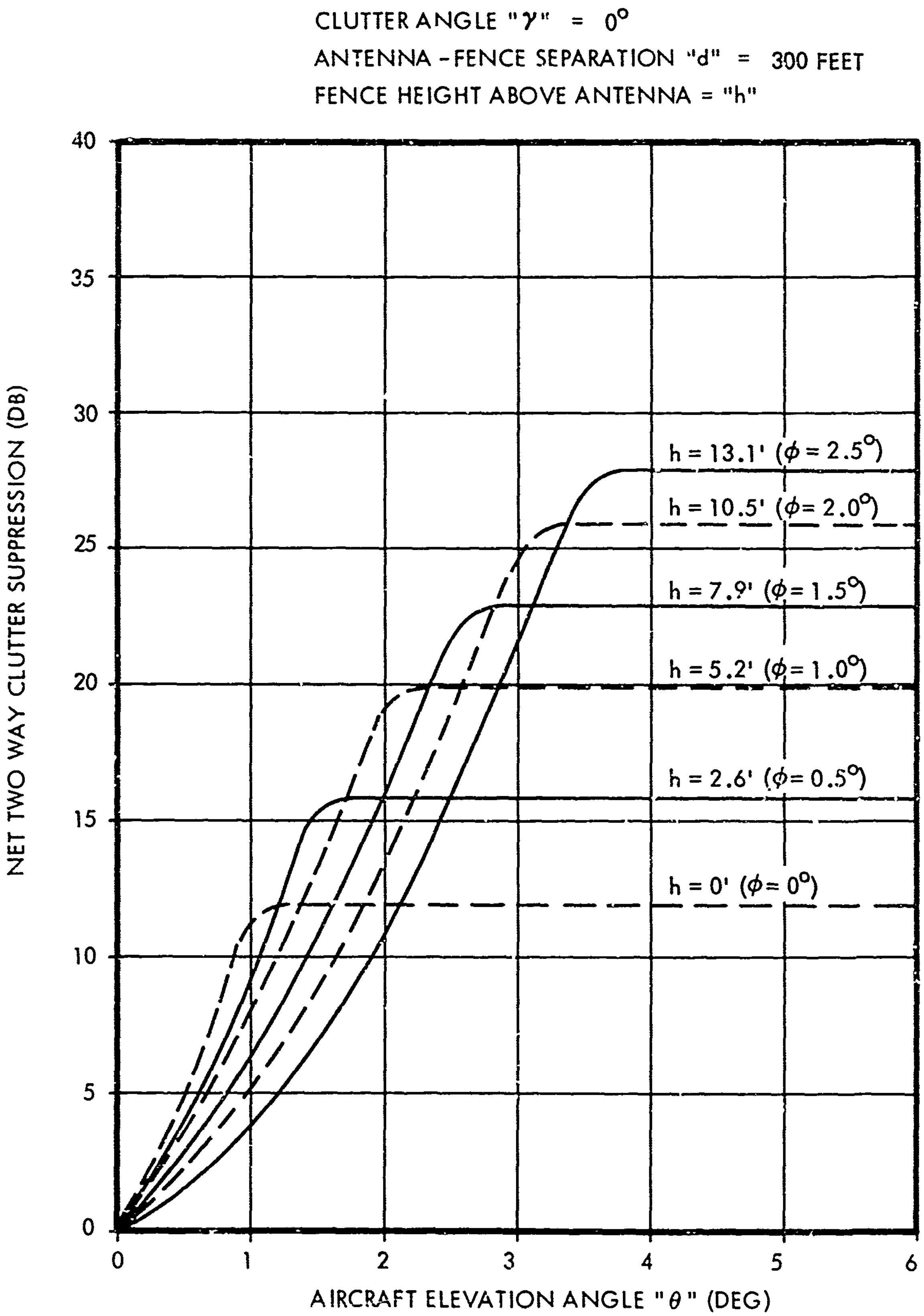


FIGURE A-4 NET TWO WAY CLUTTER SUPPRESSION FOR SIMPLE FENCES

CLUTTER ANGLE "γ" = 0°
ANTENNA - FENCE SEPARATION "d" = 400 FEET
FENCE HEIGHT ABOVE ANTENNA = "h"

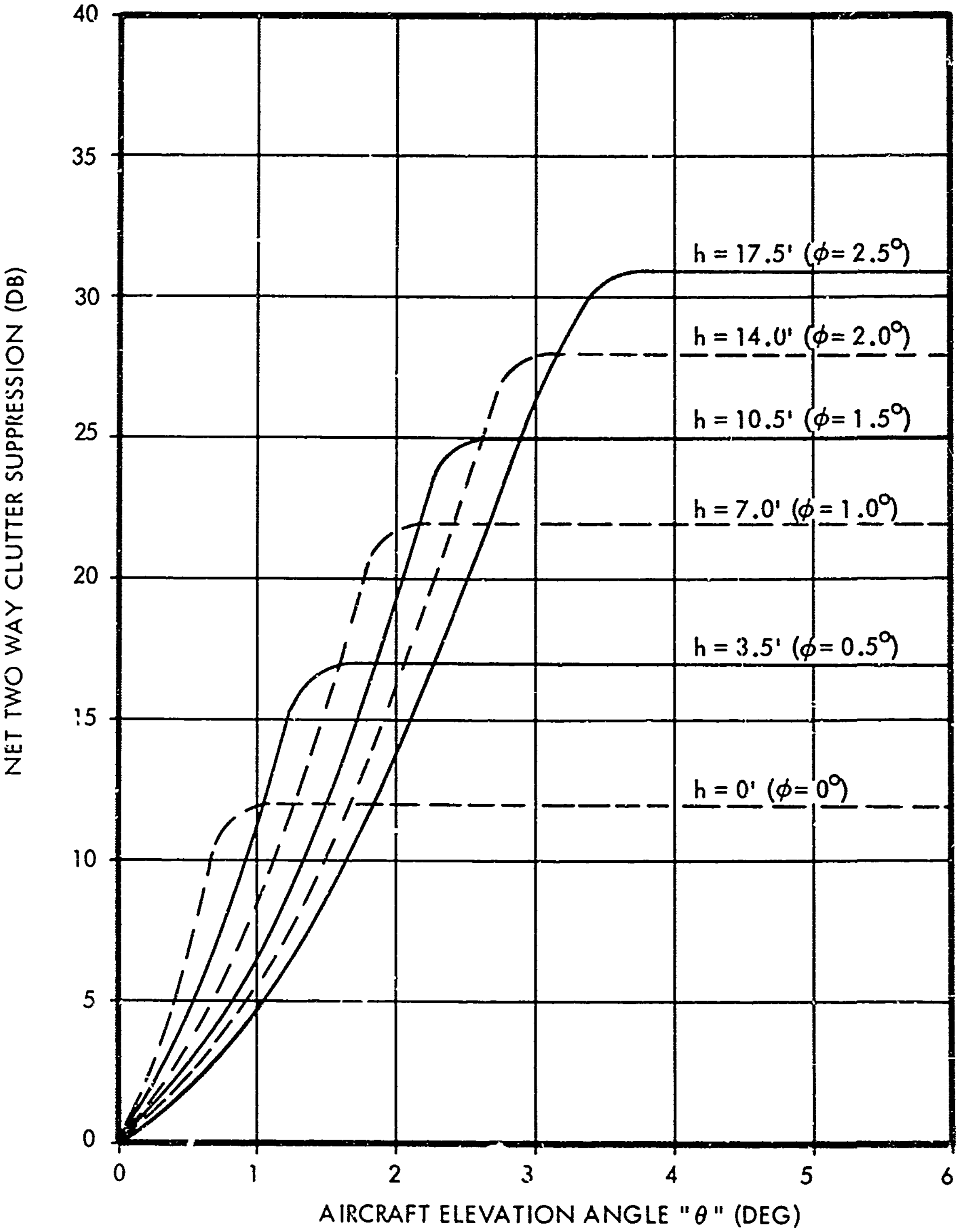


FIGURE A-5 NET TWO WAY CLUTTER SUPPRESSION FOR SIMPLE FENCES

CLUTTER ANGLE "γ" = 0°

ANTENNA - FENCE SEPARATION "d" = 800 FEET

FENCE HEIGHT ABOVE ANTENNA = "h"

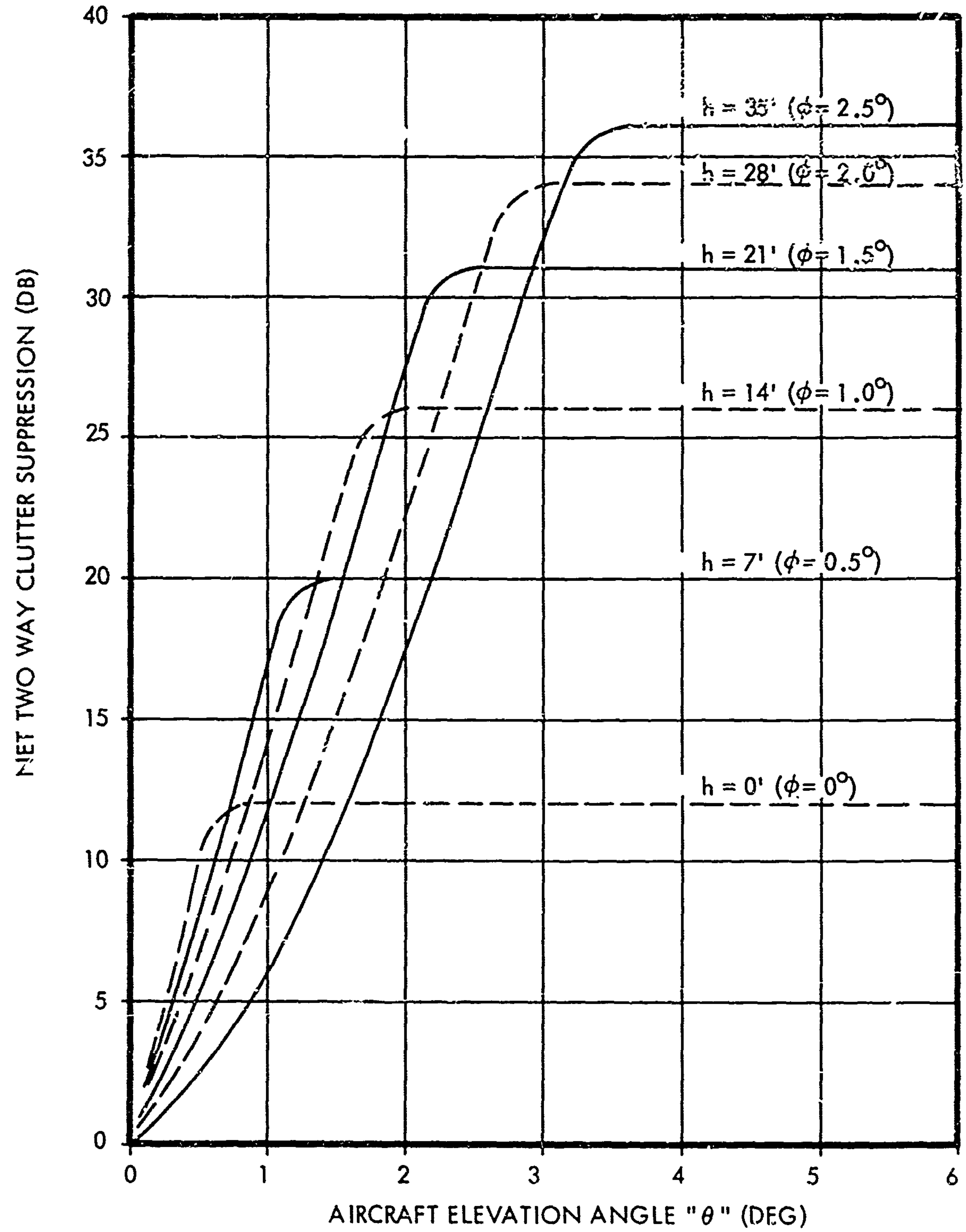


FIGURE A-6 NET TWO WAY CLUTTER SUPPRESSION FOR SIMPLE FENCES

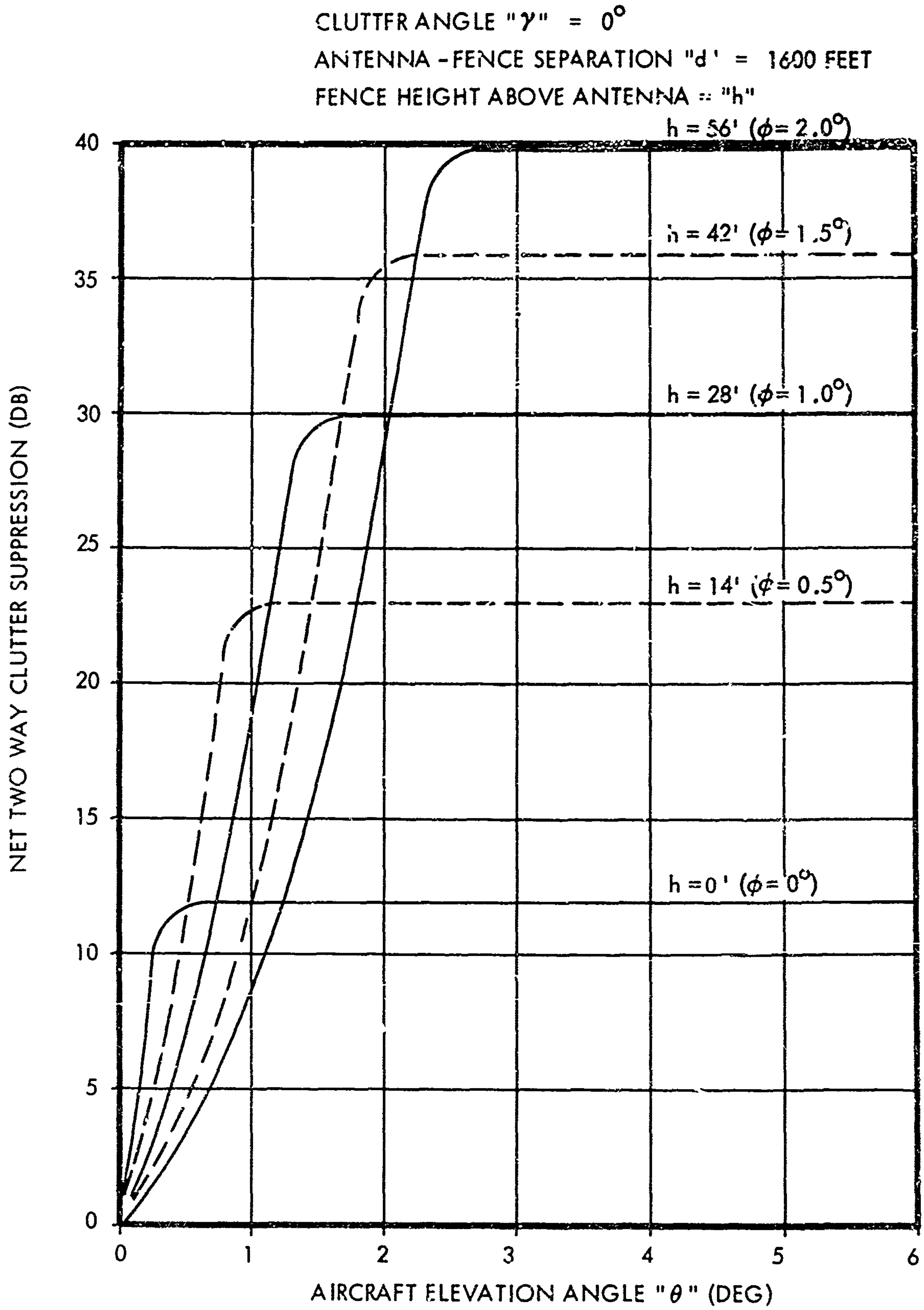


FIGURE A-7 NET TWO WAY CLUTTER SUPPRESSION FOR SIMPLE FENCES

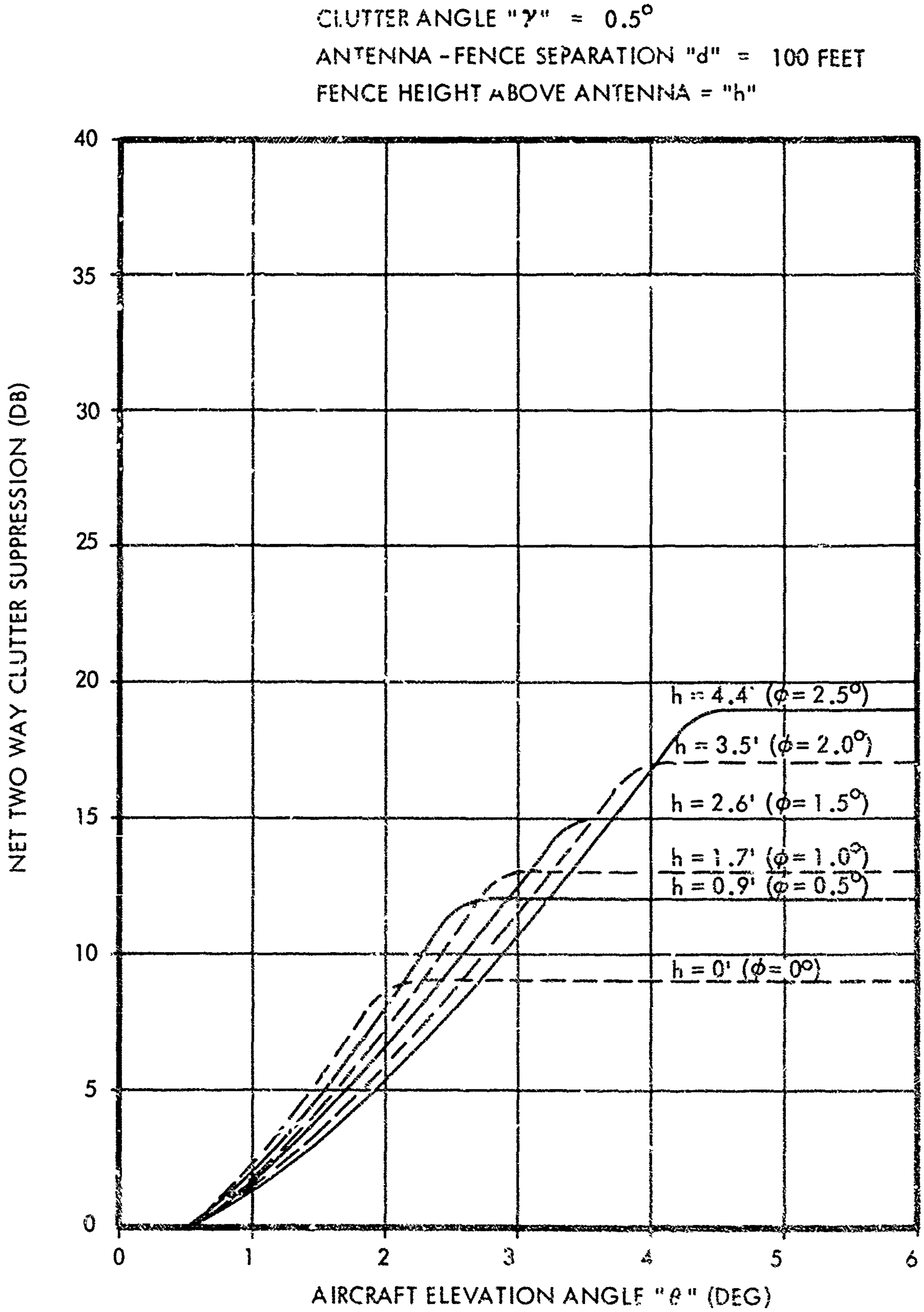


FIGURE A-8 NET TWO WAY CLUTTER SUPPRESSION FOR SIMPLE FENCES

CLUTTER ANGLE "γ" = 0.5°

ANTENNA - FENCE SEPARATION "d" = 200 FEET

FENCE HEIGHT ABOVE ANTENNA = "h"

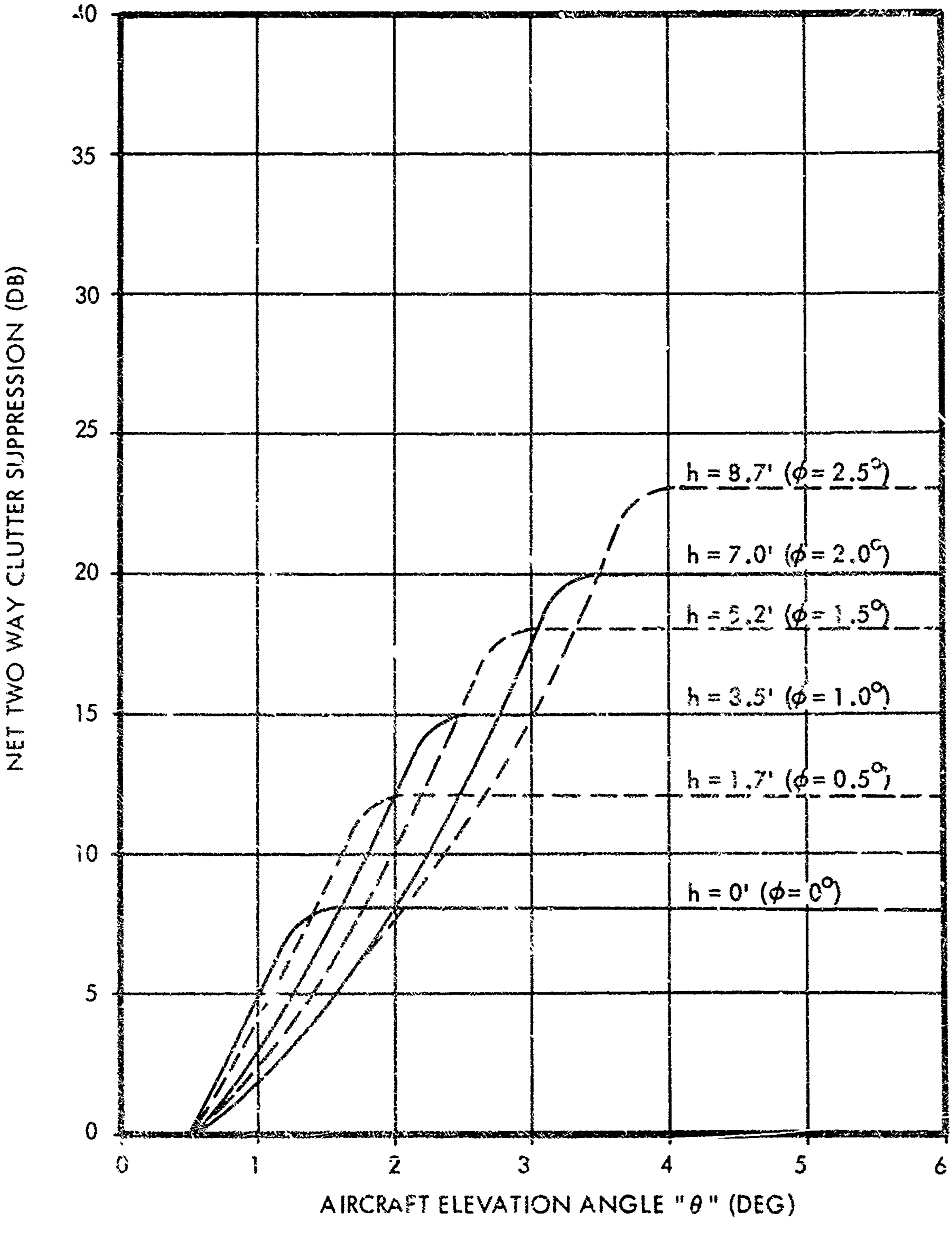


FIGURE A-9 NET TWO WAY CLUTTER SUPPRESSION FOR SIMPLE FENCES

CLUTTER ANGLE "γ" = 0.5°

ANTENNA - FENCE SEPARATION "d" = 300 FEET

FENCE HEIGHT ABOVE ANTENNA = "h"

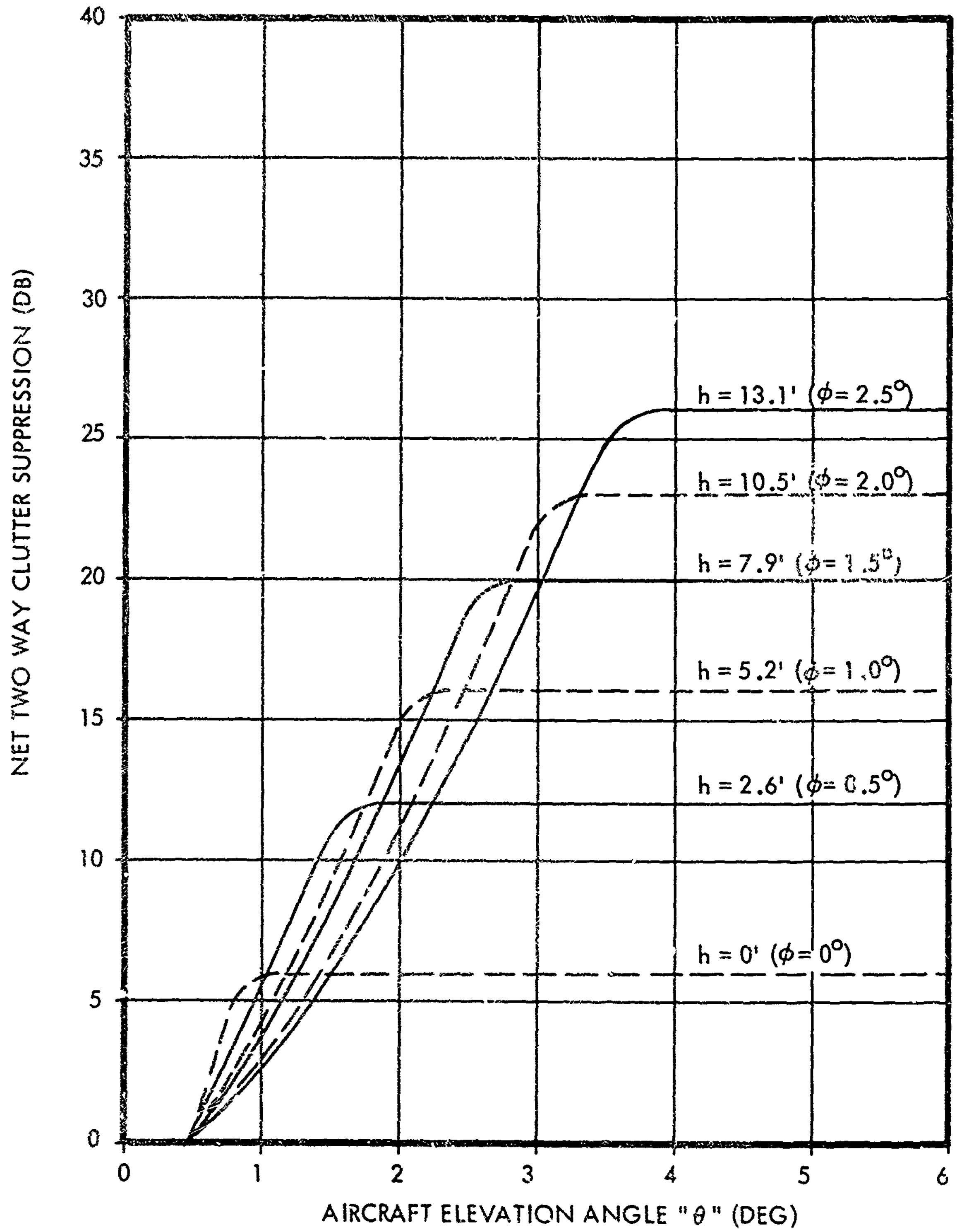


FIGURE A-10 NET TWO WAY CLUTTER SUPPRESSION FOR SIMPLE FENCES

CLUTTER ANGLE "γ" = 0.5°
ANTENNA - FENCE SEPARATION "d" = 400 FEET
FENCE HEIGHT ABOVE ANTENNA = "h"

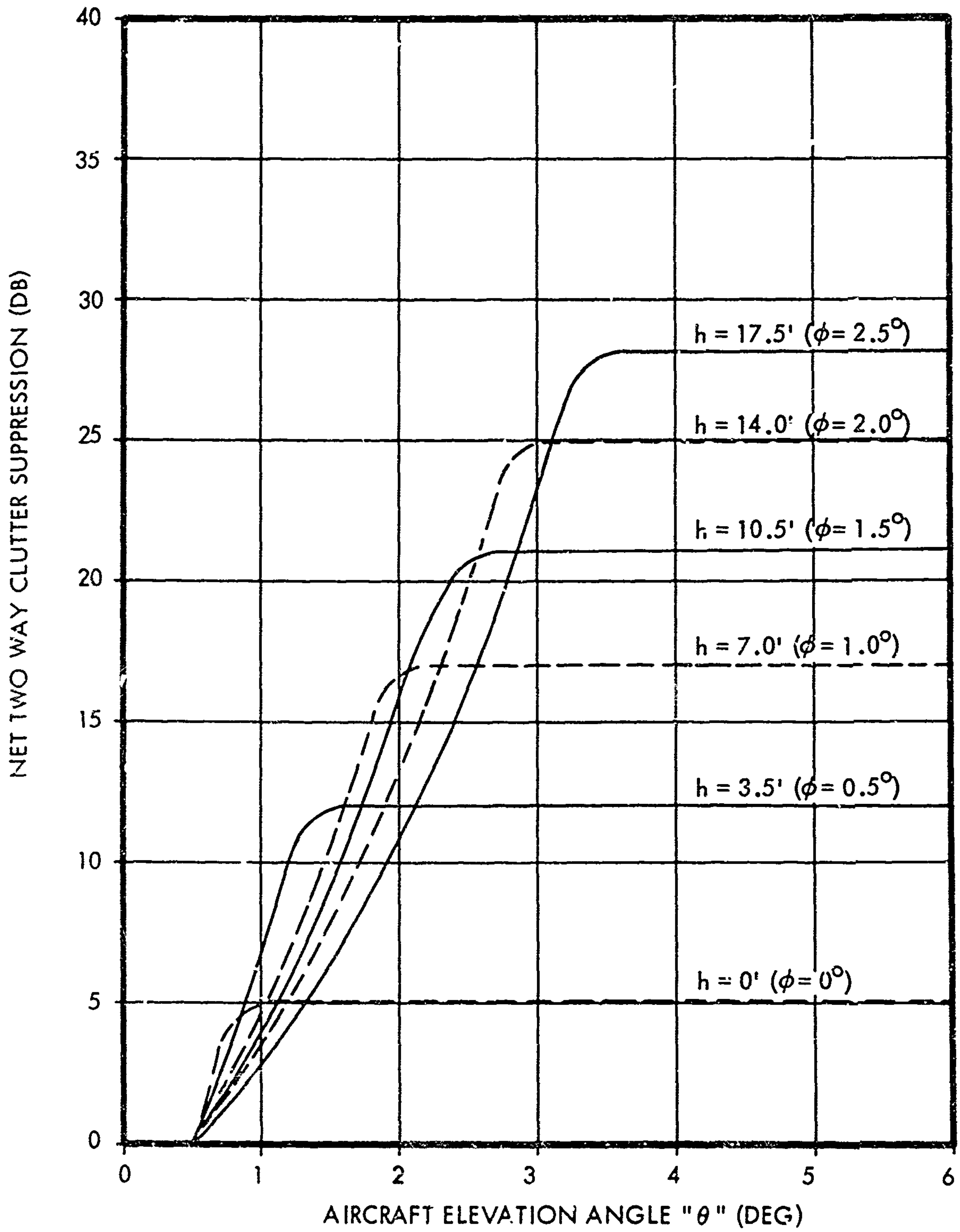


FIGURE A-11 NET TWO WAY CLUTTER SUPPRESSION FOR SIMPLE FENCES

CLUTTER ANGLE "γ" = 0.5°

ANTENNA - FENCE SEPARATION "d" = 800 FEET

FENCE HEIGHT ABOVE ANTENNA = "h"

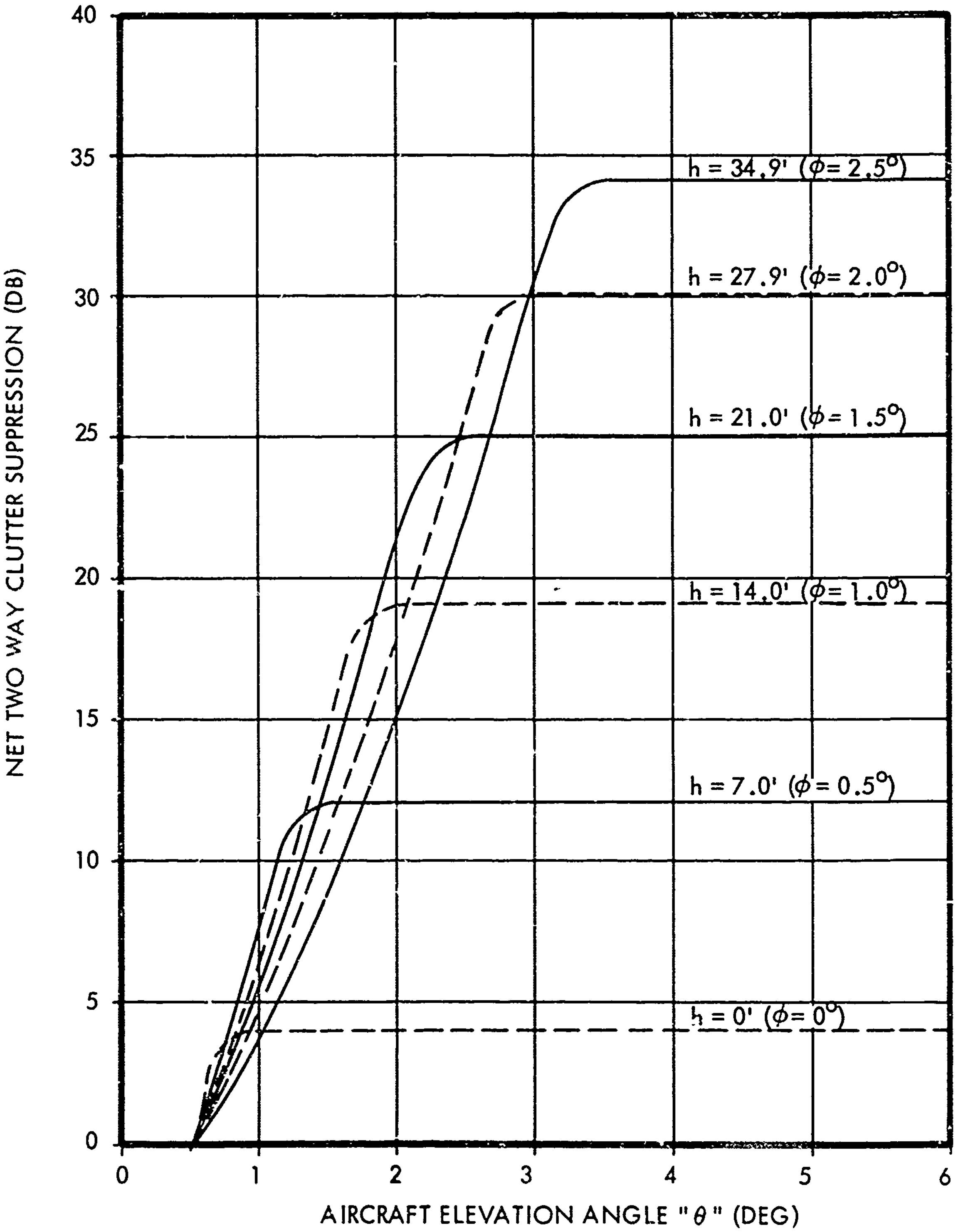


FIGURE A-12 NET TWO WAY CLUTTER SUPPRESSION FOR SIMPLE FENCES

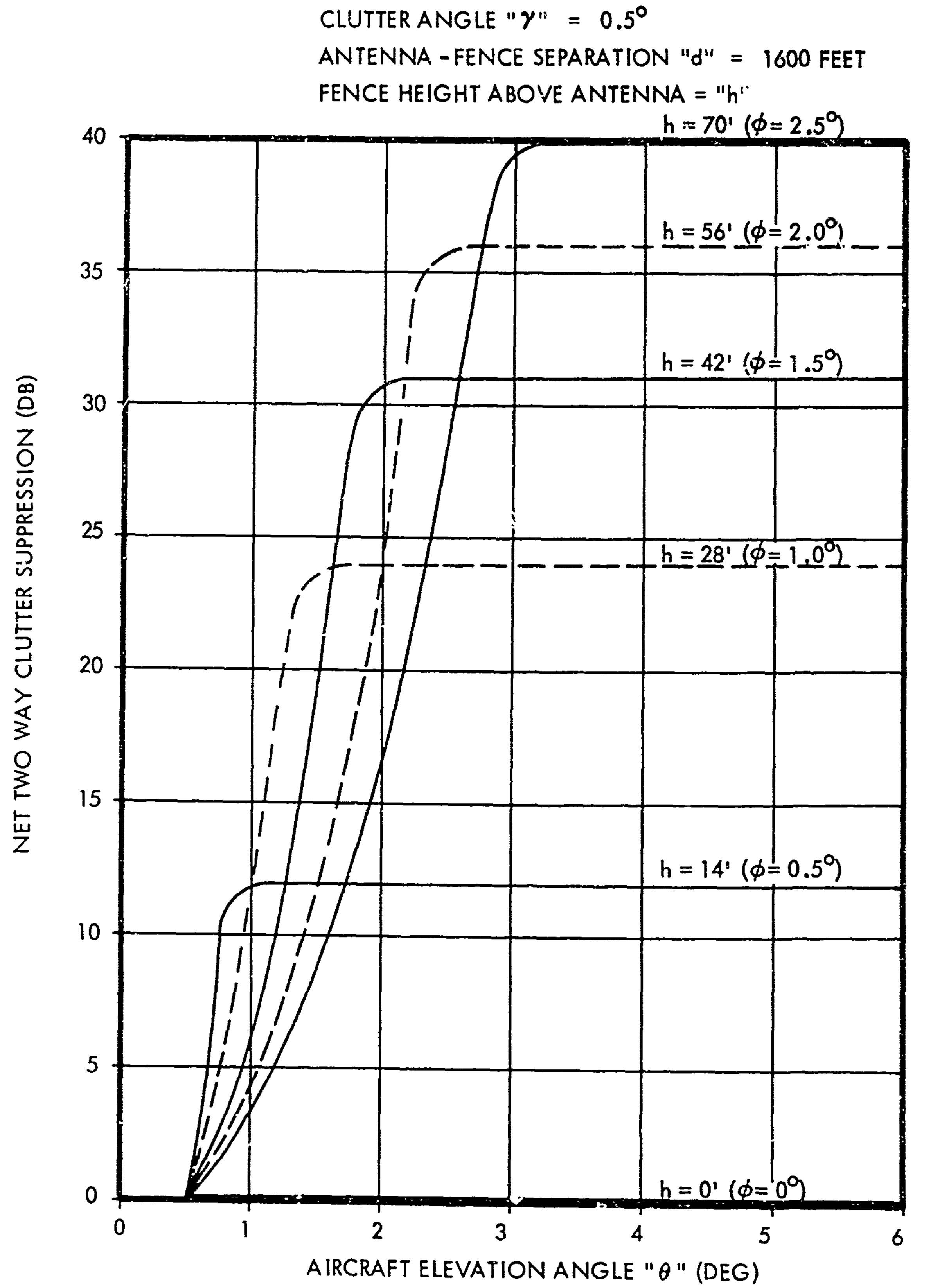


FIGURE A-13 NET TWO WAY CLUTTER SUPPRESSION FOR SIMPLE FENCES

CLUTTER ANGLE "γ" = 1.0°

ANTENNA - FENCE SEPARATION "d" = 100 FEET

FENCE HEIGHT ABOVE ANTENNA = "h"

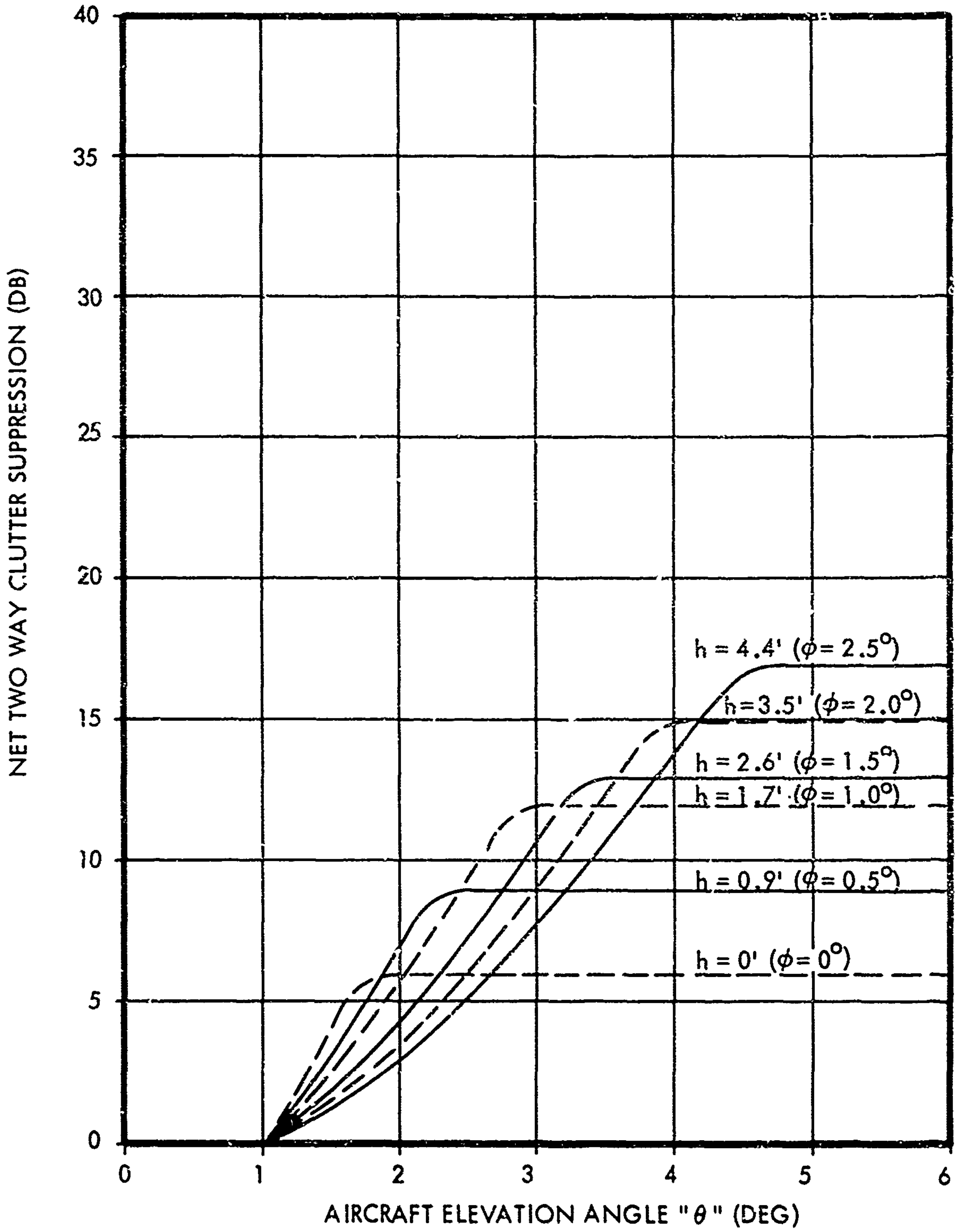


FIGURE A-14 NET TWO WAY CLUTTER SUPPRESSION FOR SIMPLE FENCES

CLUTTER ANGLE "γ" = 1.0°
ANTENNA-FENCE SEPARATION "d" = 200 FEET
FENCE HEIGHT ABOVE ANTENNA = "h"

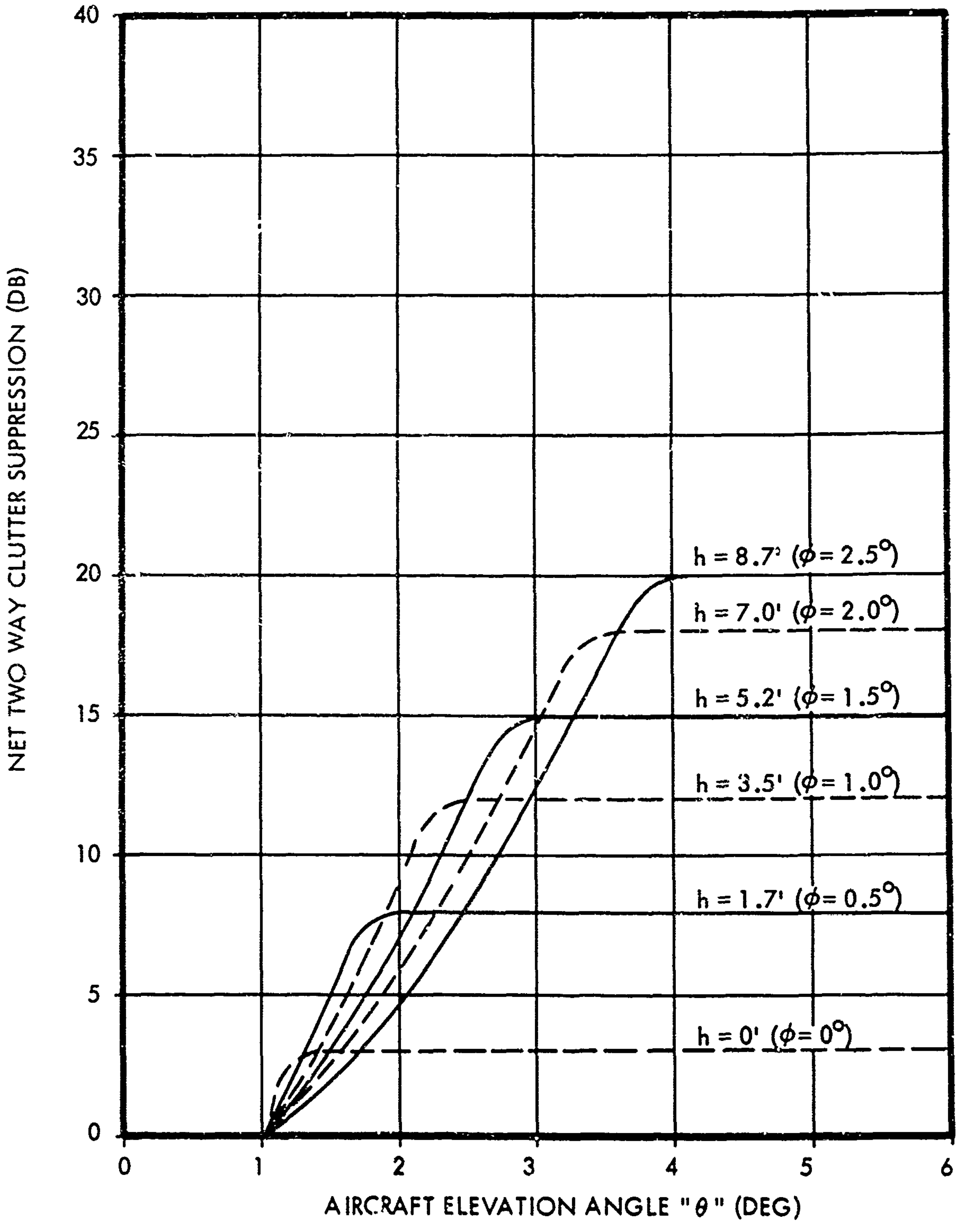


FIGURE A-15 NET TWO WAY CLUTTER SUPPRESSION FOR SIMPLE FENCES

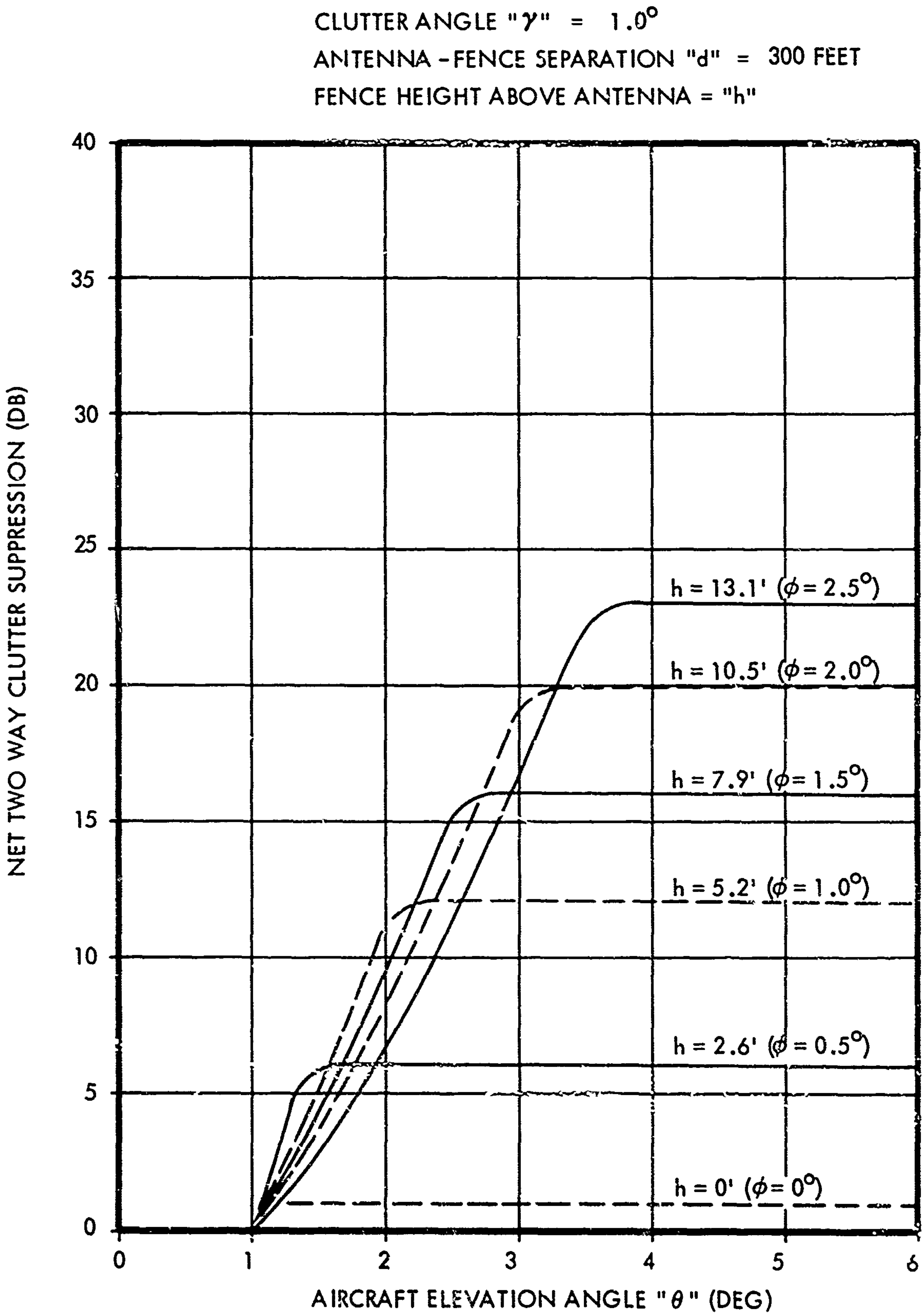


FIGURE A-16 NET TWO WAY CLUTTER SUPPRESSION FOR SIMPLE FENCES

CLUTTER ANGLE "γ" = 1.0°
ANTENNA - FENCE SEPARATION "d" = 400 FEET
FENCE HEIGHT ABOVE ANTENNA = "h"

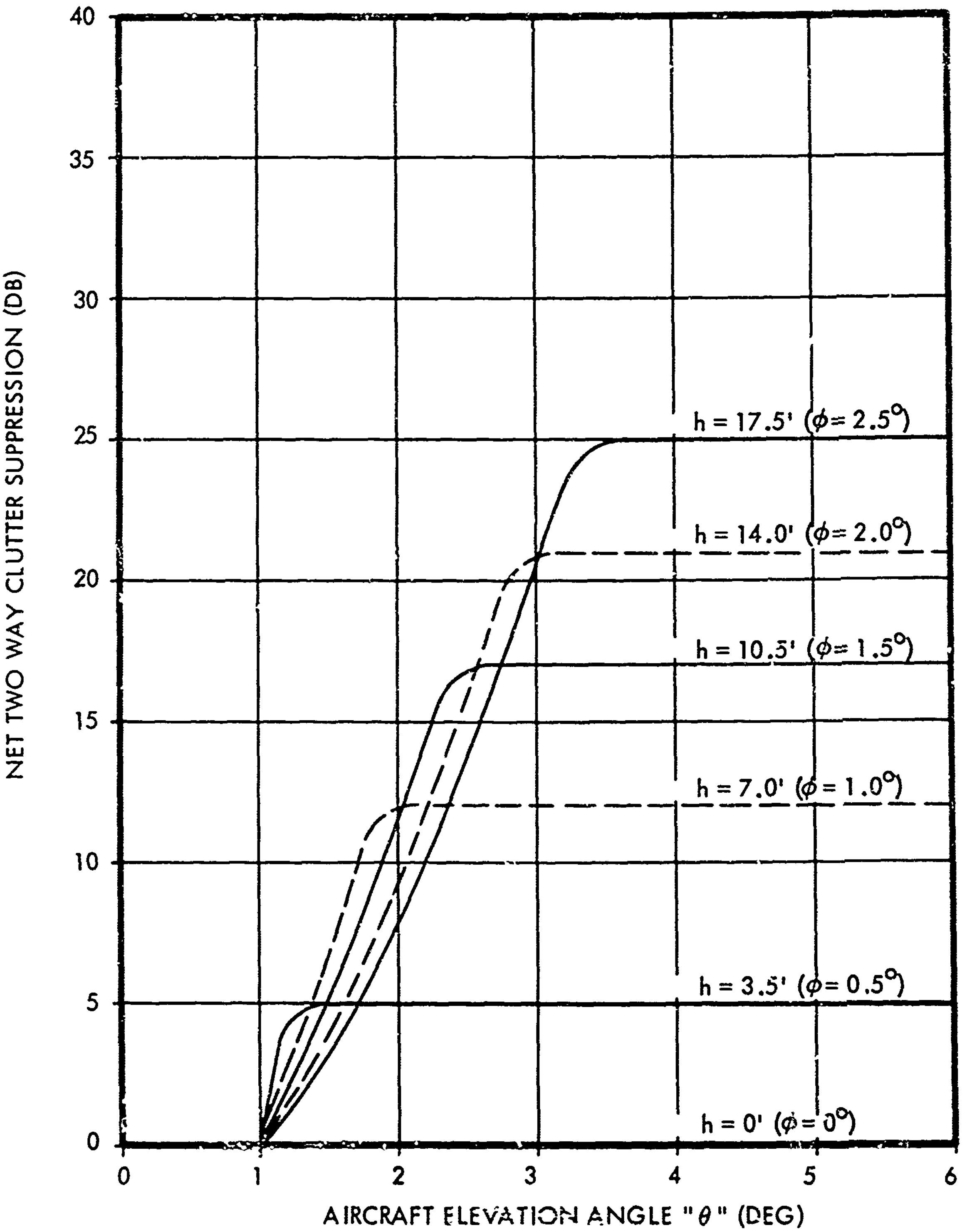


FIGURE A-17 NET TWO WAY CLUTTER SUPPRESSION FOR SIMPLE FENCES

CLUTTER ANGLE "γ" = 1.0°

ANTENNA - FENCE SEPARATION "d" = 800 FEET

FENCE HEIGHT ABOVE ANTENNA = "h"

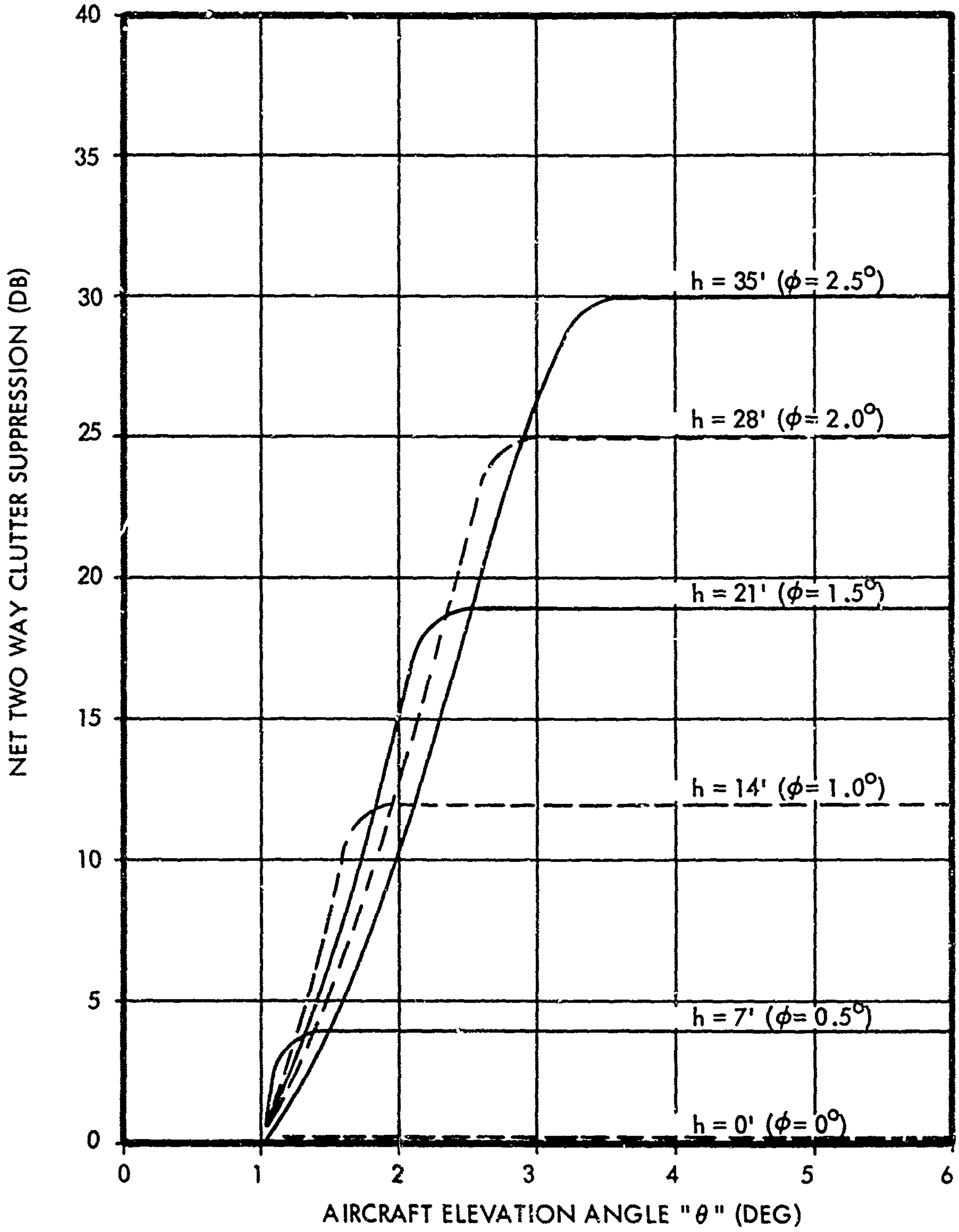


FIGURE A-18 NET TWO WAY CLUTTER SUPPRESSION FOR SIMPLE FENCES

CLUTTER ANGLE "γ" = 1.0°
ANTENNA - FENCE SEPARATION "d" = 1600 FEET
FENCE HEIGHT ABOVE ANTENNA = "h"

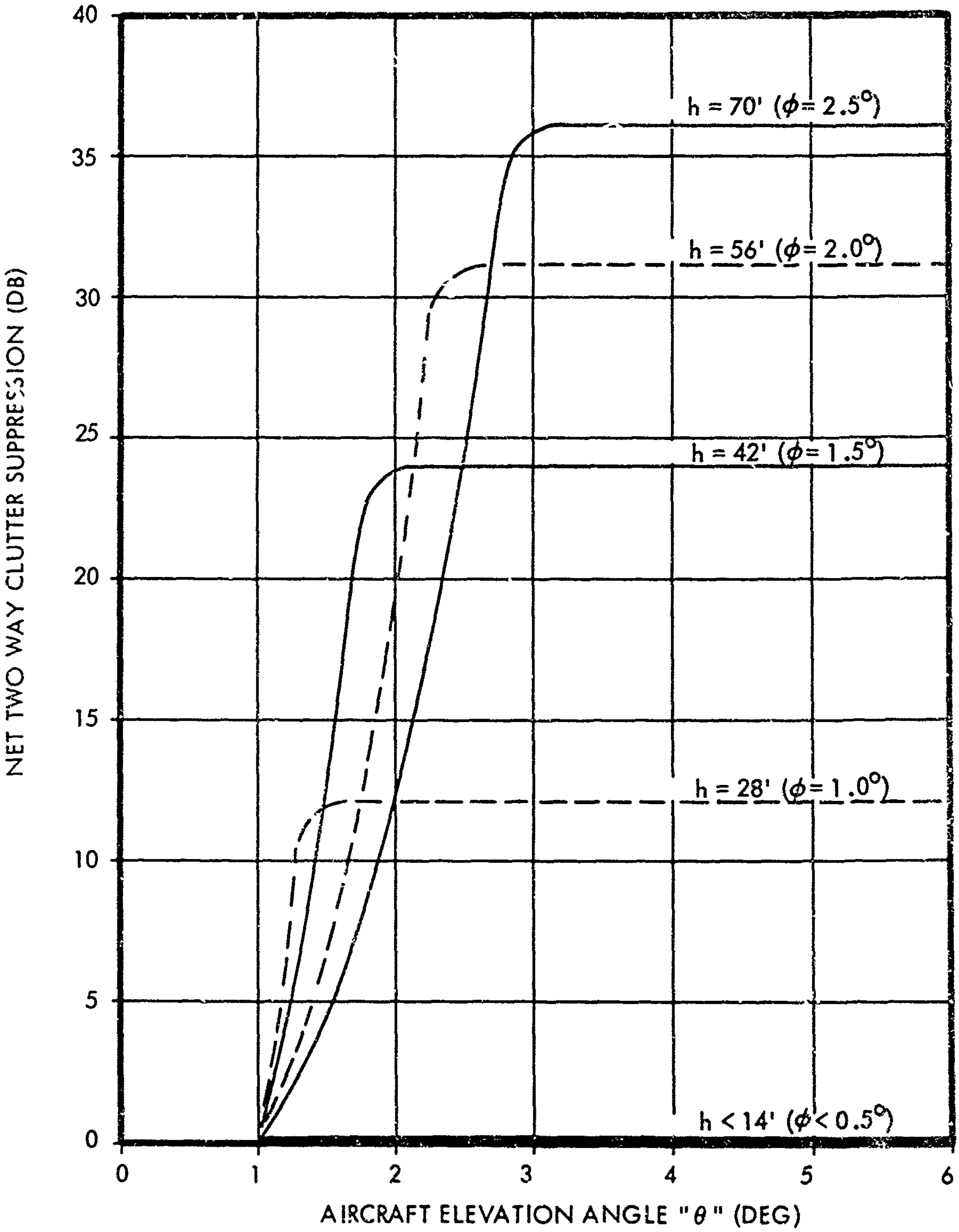


FIGURE A-19 NET TWO WAY CLUTTER SUPPRESSION FOR SIMPLE FENCES

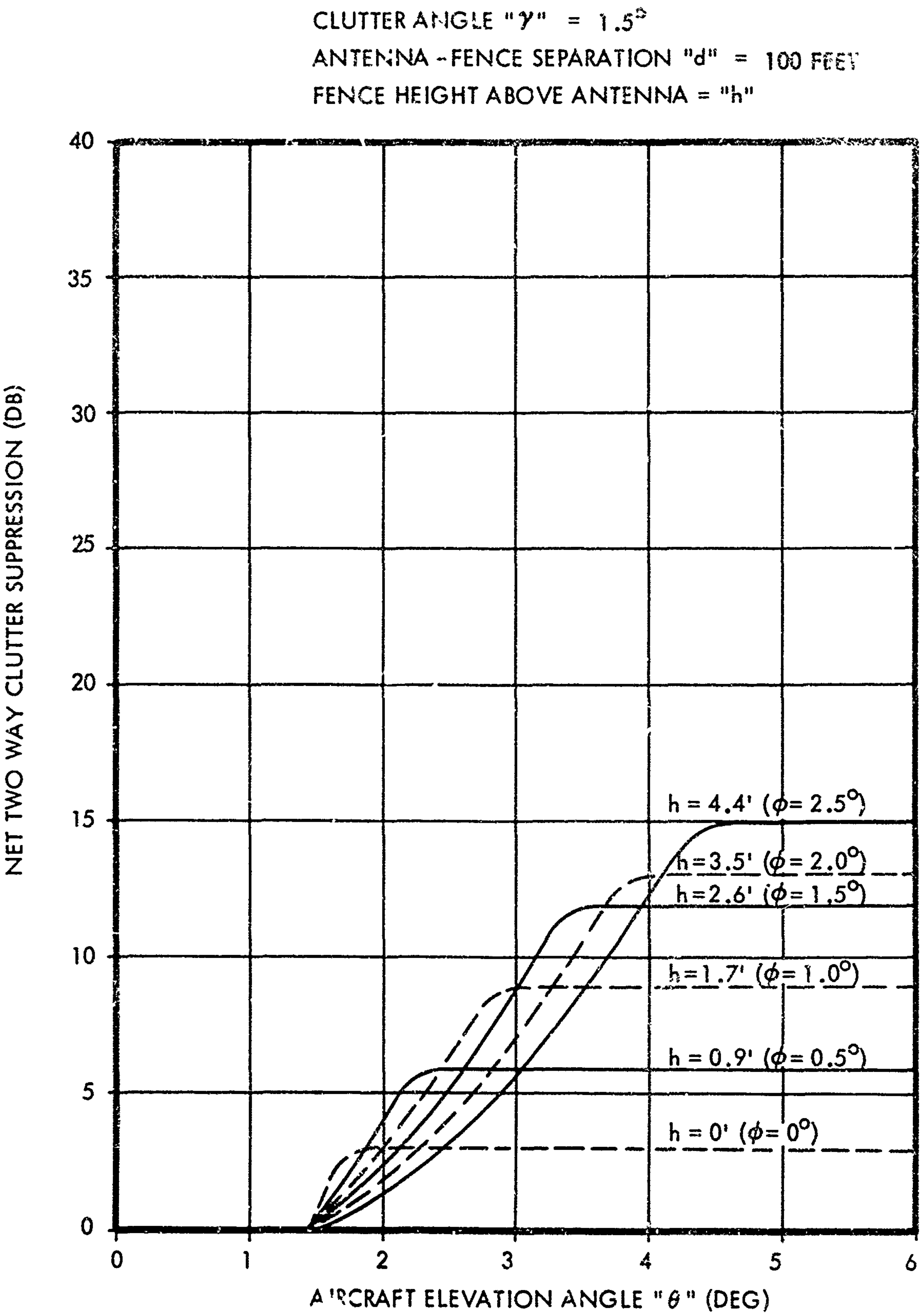


FIGURE A-20 NET TWO WAY CLUTTER SUPPRESSION FOR SIMPLE FENCES

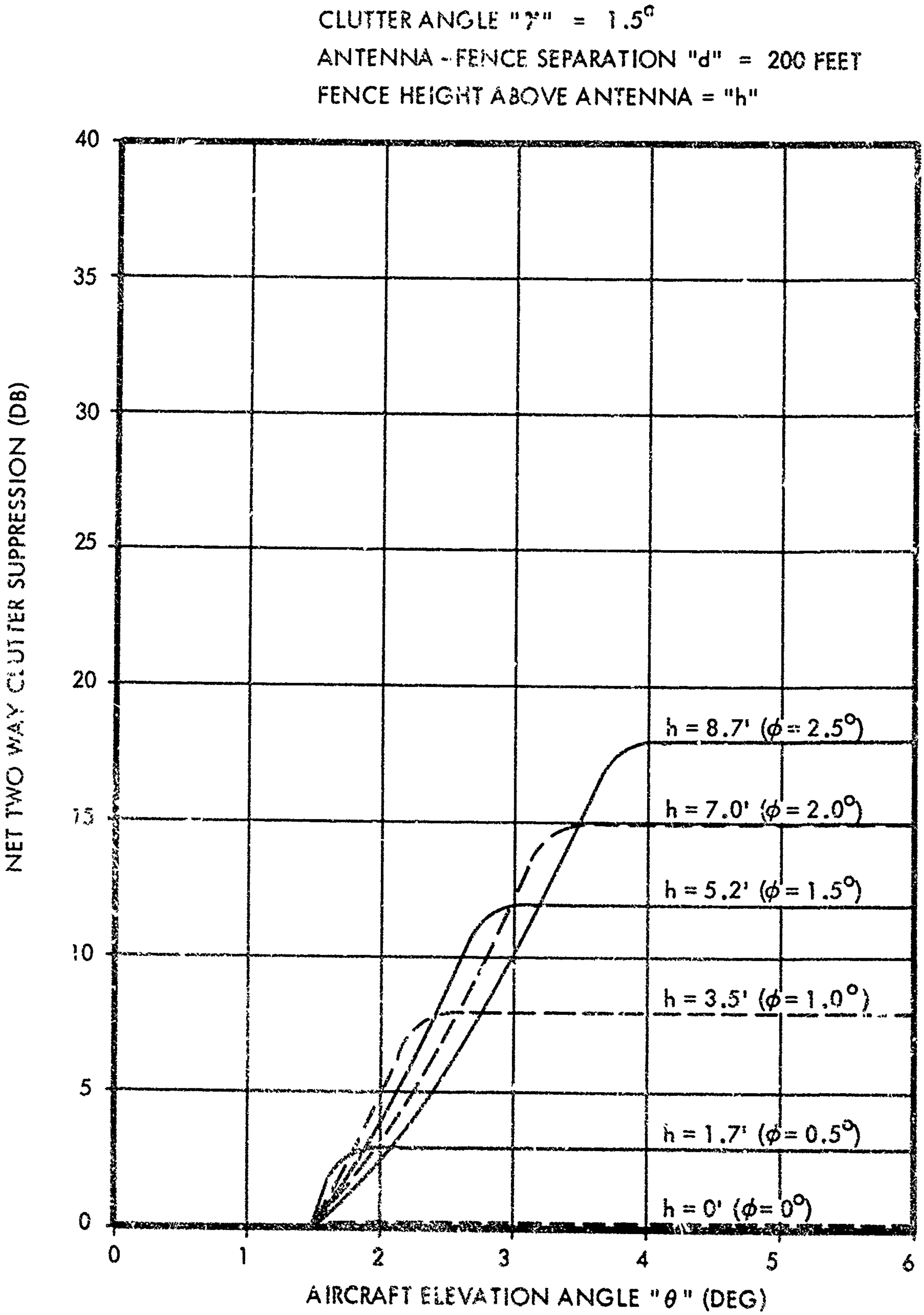


FIGURE A-21 NET TWO WAY CLUTTER SUPPRESSION FOR SIMPLE FENCES

CLUTTER ANGLE "γ" = 1.5°
ANTENNA - FENCE SEPARATION "d" = 300 FEET
FENCE HEIGHT ABOVE ANTENNA = "h"

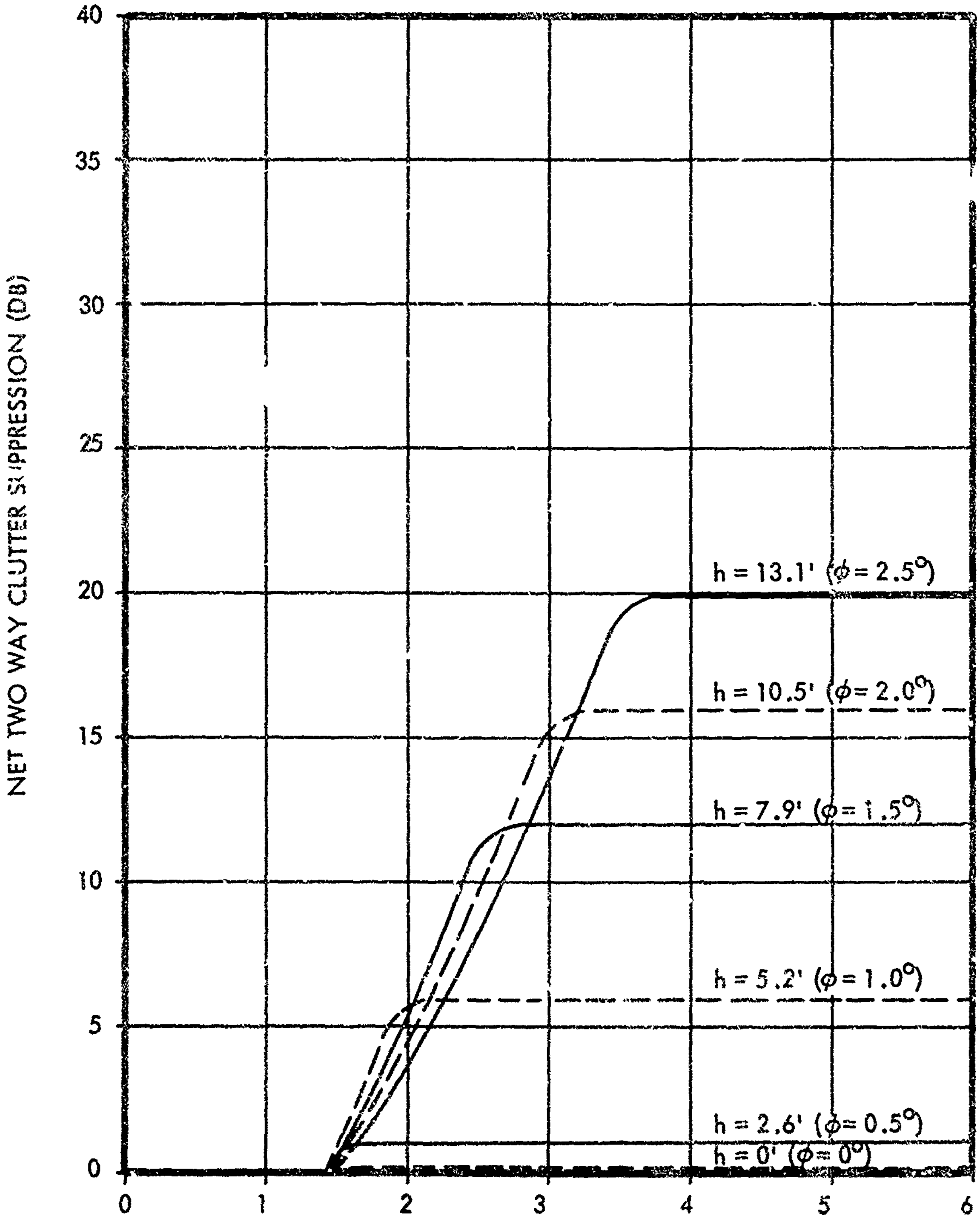


FIGURE A-22 NET TWO WAY CLUTTER SUPPRESSION FOR SIMPLE FENCES

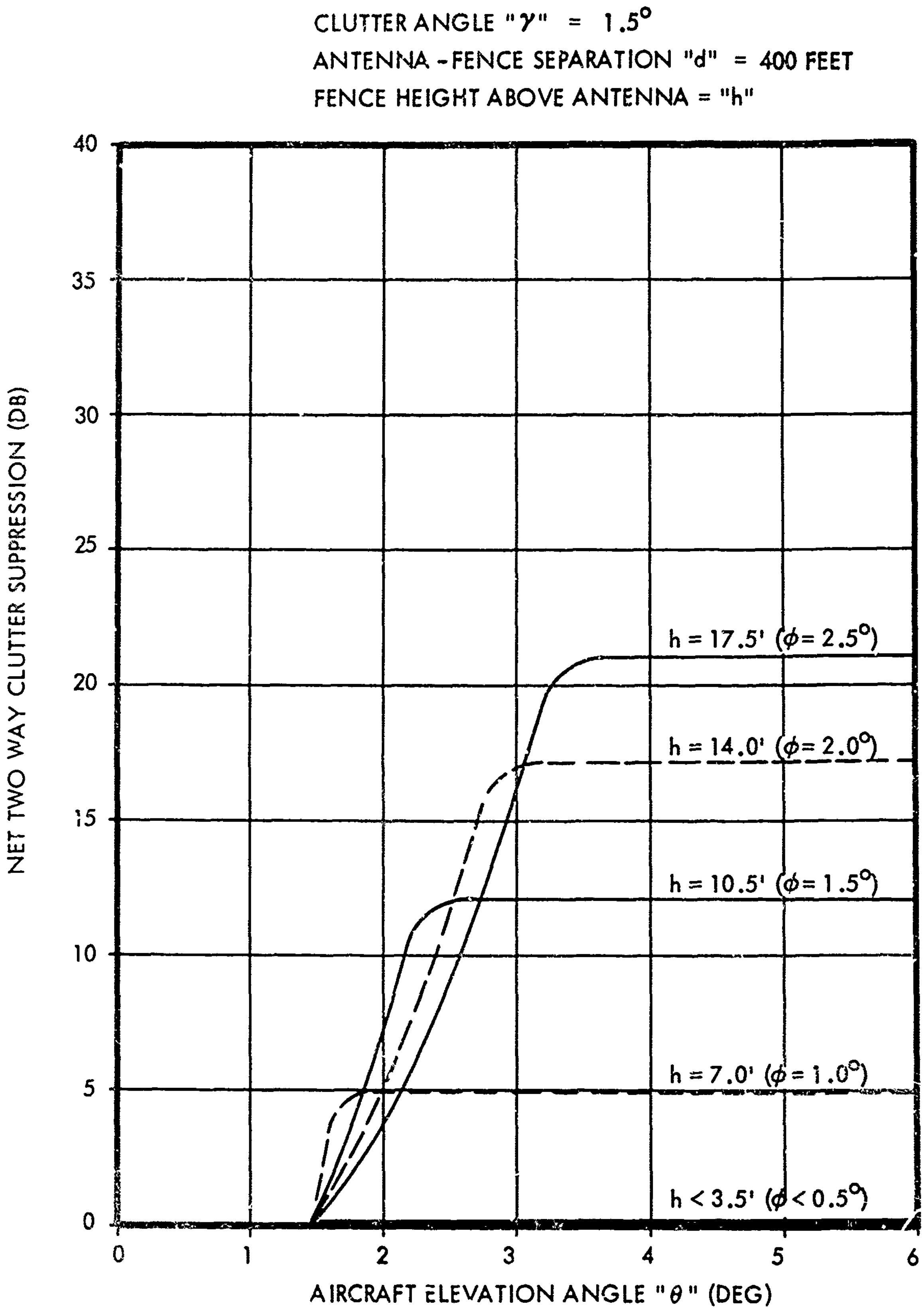


FIGURE A-23 NET TWO WAY CLUTTER SUPPRESSION FOR SIMPLE FENCES

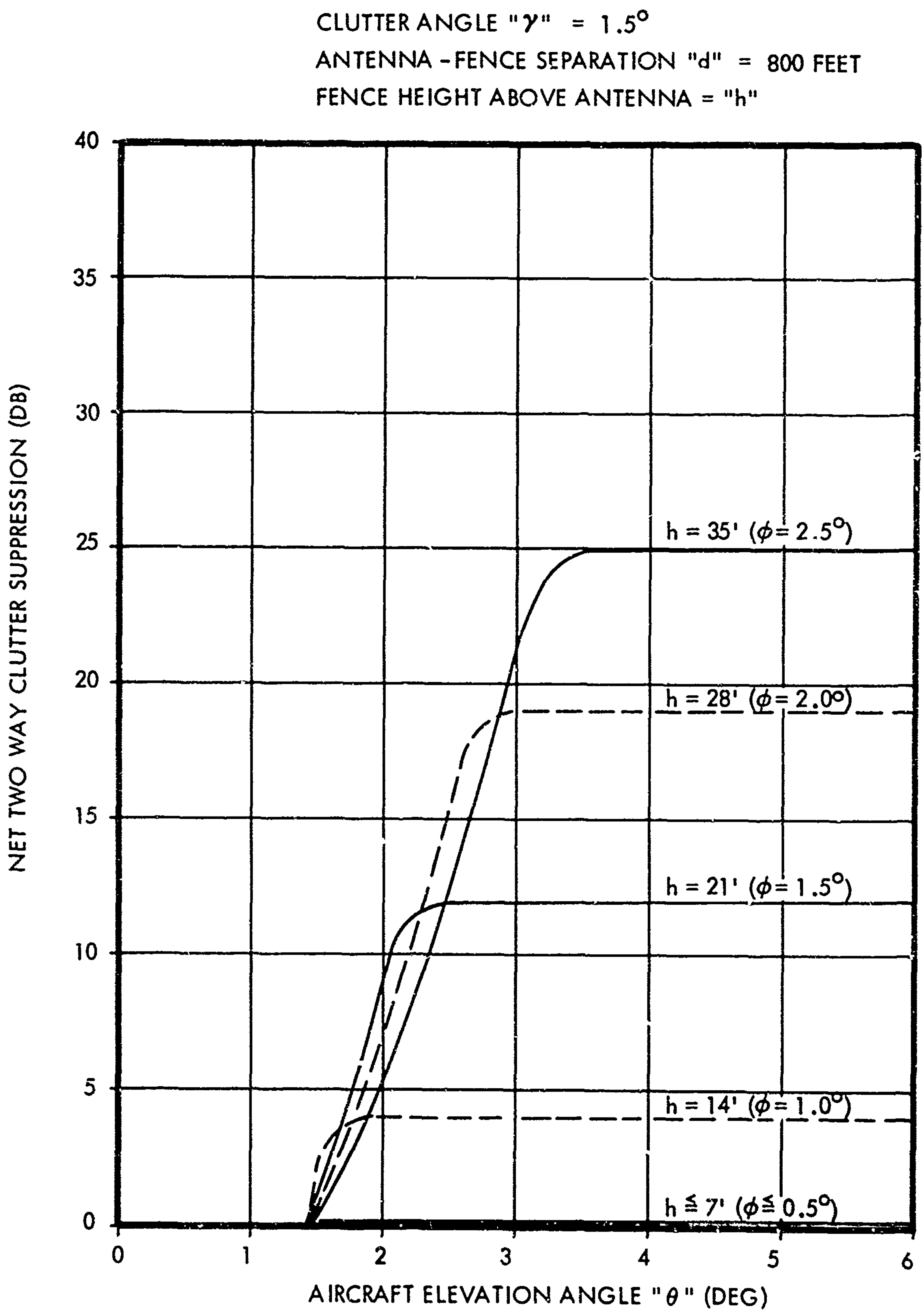
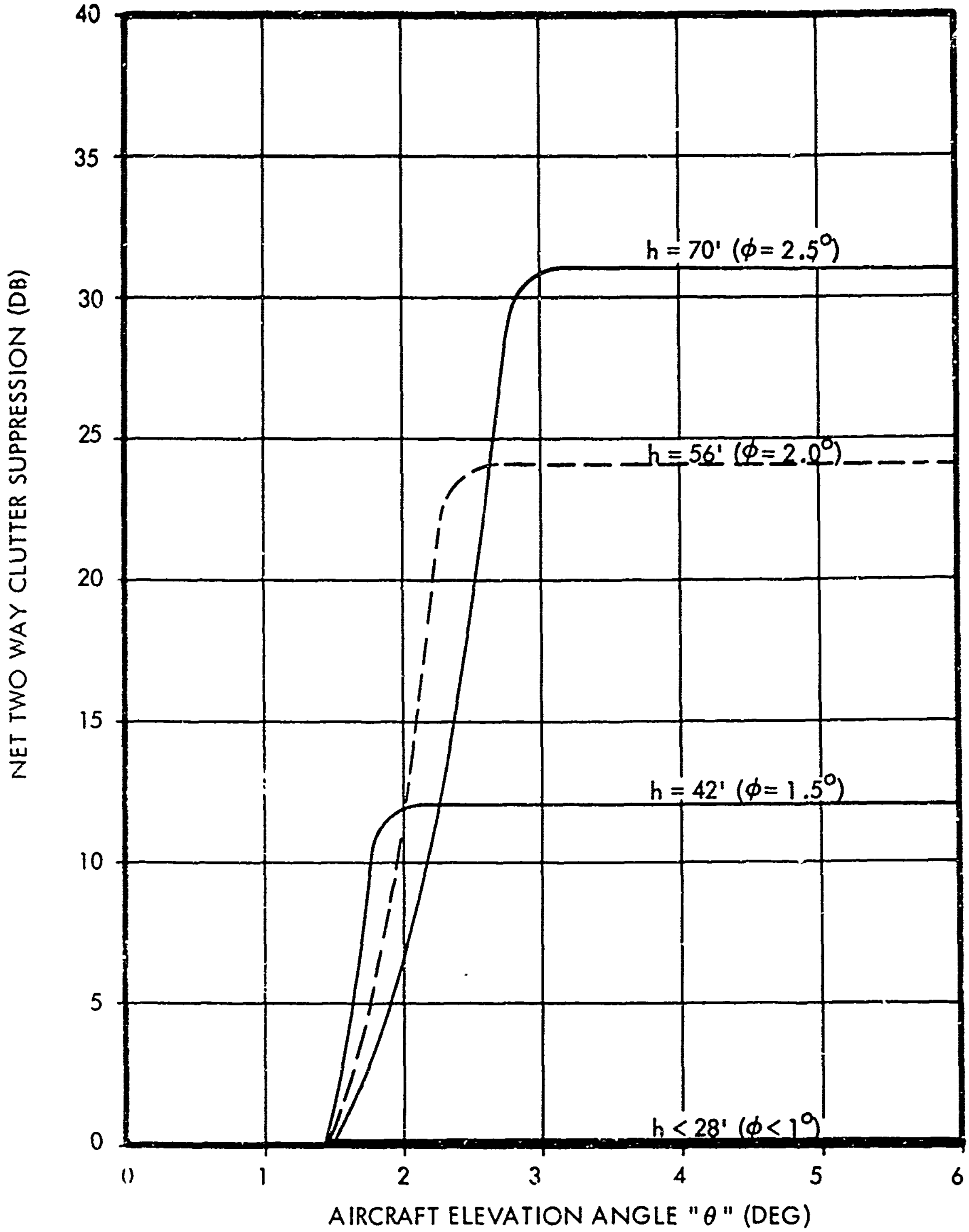


FIGURE A-24 NET TWO WAY CLUTTER SUPPRESSION FOR SIMPLE FENCES

CLUTTER ANGLE "γ" = 1.5°
ANTENNA - FENCE SEPARATION "d" = 1600 FEET
FENCE HEIGHT ABOVE ANTENNA = "h"



UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title body of abstract and indexing annotation must be entered when the overall report is classified)

1 ORIGINATING ACTIVITY (Corporate author) ITT/Gilfillan Inc. 7821 Orion Street Van Nuys, California 91405	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3 REPORT TITLE

RADIO FREQUENCY FENCE FOR GCA RADAR AT PHAN RANG, RVN

4 DESCRIPTIVE NOTES (Type of report and inclusive dates)

Final Technical Report

5 AUTHOR(S) (First name, middle initial, last name)

Mr. R. J. Hanratty
Mr. L. H. Sacks
Mr. W. J. Hunter

6 REPORT DATE	7a TOTAL NO. OF PAGES	7b. NO. OF REFS
March 1970	77	4

8a CONTRACT OR GRANT NO F30602-69-C-0069 b. PROJECT NO 1559 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) 793-00000 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) RADC-TR-69-2

10 DISTRIBUTION STATEMENT

Each transmittal of this document outside the agencies of the U.S. Government must have prior approval of RADC (EMAED), GAFB, NY 13440.

11 SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Rome Air Development Center (EMAED) Griffiss Air Force Base, New York 13440.

13 ABSTRACT

Two "simple" rf fences are recommended for installation at the Phan Rang GCA radar site to provide 20 db clutter rejection for the S-band ASR. The dimensions of the fences, their locations and performance are based on the clutter rejection requirements, clutter profile, and aircraft radar-approach paths. Modular construction techniques for the fences results in minimum cost, rapid fabrication mobility, easy storage, and high mechanical performance. Double-mesh screening minimizes X-band attenuation through the fence so that the X-band PAR performance is not deteriorated by the fence. The universality of the fence design allows the fence to be individually tailored to the requirements of most sites where clutter return is a problem.

DD FORM 1 NOV 65 1473

UNCLASSIFIED
Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
GCA Radar						
Radio Frequency Fence						
Clutter Rejection						

AFLC—Griffiss AFB NY 8 Jun 70-62